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STUDY OF THE ECONOMICS OF HOSPITAL SOLID WASTE SYSTEMS

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STUDY OF THE ECONOMICS OF HOSPITAL SOLID WASTE SYSTEMS

By

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This study attempts to develop a methodology for comparing hospital solid waste handling systems from a point of view which considers both the operational and the social costs. The problem is laid out as a decision tree, where nodes of the tree represent decision points at stages of hospital waste handling, and branches at any node represent the different systems available at that point. Cost functions are developed for each alternative, with hospital characteristics and performance standards as parameters in the functions. The optimal system minimizes the total cost of collection, treatment and transportation to the point of final disposal, while maintaining the prescribed performance standards. A model of a centralized incineration system, which combines the waste hauling and treatment systems of hospitals in an area, is developed and applied to hospitals in the Minneapolis and St. Paul metropolitan area.

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

In an attempt to solve the problem of solid waste disposal, this study examines the hospital solid waste handling systems. This report published by the National Environmental Research Center - Cincinnati attempts to develop a rational basis for comparing hospital solid waste handling systems from a total system perspective which considers both operational and social costs.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center - Cincinnati

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ABSTRACT

Study of Economics of Hospital Solid Waste Systems

This study attempts to develop a methodology for comparing hospital solid waste handling systems from a point of view which considers both the operational and the social costs.

To avoid controversial and difficult problems involved in quantifying social costs, the approach adopted has been to prescribe minimal performance standards and to select the optimal system, from the set of alternatives which comply with the minimal standards, on the basis of cost alone.

The problem is laid out as a decision tree, where nodes of the tree represent decision points at stages of hospital waste handling, and branches at any node represent the different systems available at that point. Cost functions are developed for each alternative, with hospital characteristics and performance standards as parameters in the functions. The optimal system minimizes the total cost of collection, treatment and transportation to the point of final disposal, while maintaining the prescribed performance standards.

A model of a centralized incineration system, which combines the waste hauling and treatment systems of hospitals in an area, is developed and applied to hospitals in the Minneapolis and St. Paul metropolitan area.

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CHAPTER I

INTRODUCTION AND METHODOLOGY

1.1 Concern for Environment

An apparent shift taking place in the value system of the American public places very high priority on improving the physical and social environment. That new value system strongly supports the idea that economic growth alone should not be the objective of public policy. Instead, human welfare, as recognized by classical economics, should be the proper goal of a public policy where due recognition is given to the social overhead costs. Some environmentalists even extend the argument that growth of the Nation's economy, diminishes the social well-being. Even normally conservative elements of our society[19] strongly support the environmental protection concept today. Now a widely accepted opinion is that the natural environment should no longer be treated as a free commodity, but instead its use should be managed according to its scarcity.

1.2 Hospital Solid Waste Management

Unfortunately, the general public, even most environmentalists, are unaware of the magnitude and importance of handling solid wastes in public buildings, particularly in hospitals. In most hospitals today, facilities for handling solid waste are antiquated. More precisely, the development of the design basis in hospitals for solid waste systems has lagged behind the development of other operational systems. This lag is not a consequence of nonavailable technology, but rather the lack of awareness of the true importance of the problem. Many hospital administrators do not know the operational costs of their solid waste system, the adequacy of the system, or its efficacy in their particular institutional and community environment.

Traditional public attitudes toward solid waste emphasize getting the waste "out of sight, out of mind," a short-sighted attitude which fails to consider what happens to the waste when it leaves the premises where it originates. Unfortunately, hospital solid waste management echoes that negligent attitude, yet the unique composition (including infectious and pathogenic wastes) of hospital solid waste should merit special concern when management decisions are made about intermediate and final disposal practices.

The dominant mode for waste collection and transfer within hospitals has been the conventional manual push cart, facilitated in some cases by gravity chutes for faster vertical movement. In-hospital waste handling traditionally has been considered a low-level janitorial function to be performed within tight budgetary limits. Incineration and/or dumping, the most popular methods for treatment and final disposal of hospital solid waste, were similarly easy and unsophisticated disposal methods in the past. Incineration simply meant burning, and dumping meant throwing the waste into the nearest available open pit. For these reasons, hospitals historically have felt little compunction to carefully plan or evaluate a program of solid waste management.

Today's drastically changing conditions, coupled with the new value system, are challenging this historical apathy towards solid waste disposal. The public's increasing environmental consciousness has led to the adoption of various governmental regulations for protection of the environment. For example, incineration no longer means simply burning. Now regulations specify that incineration must be carried out in specially designed incinerators which comply with the ever tightening air pollution regulations. Similarly, open dumps are being replaced by sanitary landfills, relocated farther away from central cities and their hospitals, which must be operated according to minimal specified standards. Considering these changing circumstances, the hospital solid waste function no longer can be ignored but must be subjected to analysis and careful planning from the design of the hospital through the daily operation of all its services.

1.3 Problems Associated with Hospital Solid Waste Handling

Improper handling of hospital solid waste can lead to many problems, some the result of waste handling in general while others are unique to the hospital environment and the nature of hospital solid waste. Conveyance of waste through hospital corridors contributes to microbial contamination of the hospital environment. Employees receive puncture wounds from needles and other sharp wastes with alarming frequency. Waste movement through gravity chutes disperses airborne organisms and contributes to potential fire hazards. Improperly containerized waste creates unsanitary conditions during conveyance or storage. Noise, odor, aesthetic and similar problems arise according to the type of equipment used and the procedures adopted for waste handling. Furthermore, the waste generated in different service areas of a hospital cannot be kept segregated because of practical difficulties in collection and storage.[7,10,35]

The following comments give an insight into the complexity of hospital solid waste handling:

> "The complexity of the waste handling operation, even in a relatively small hospital, became obvious. The wastes are handled by patients, doctors, nurses, housekeeping maids, janitors, laundry workers, visitors, technicians, orderlies and aides. They are stored in wastebaskets, GI cans, laundry hampers, carts, buckets, and on the floor. Some are wrapped and some are loose. Some wastes are wet, some bloody, some heavily contaminated, some fairly clean. Some wastes are stored in the patients' rooms, some in utility areas, some at the bottom of chutes and some in incinerator rooms. The wastes traverse the hospital in every horizontal direction and vertically. Some are moved by gravity and some by elevator. The personnel handling wastes have nearly unlimited access to all areas of the hospital. Above all, perhaps, is the phenomenon of continuous generation of waste throughout a 24-hour period and sporadic collection of the waste at fixed intervals during the day shift." [6]

Both specific air pollution effects and general air degradation can result from hospital solid waste disposal. Improper incineration adds particulates and gases to the air. Bohne reported damage to vegetation due to hydrochloric emissions from hospital incinerators.[5] Sometimes pathogens survive incineration, another form of air pollution. Physical danger to incinerator operators occasionally has been mentioned as another problem, and in one instance an operator was blinded by an exploding aerosol can. The spontaneous combustion of waste dumped in landfills also can lead to air pollution.

Land disposal poses other problems, too. Seepage from dumped waste can pollute underground water. Insect and rodent breeding problems result from waste that is not buried and compacted frequently. Children reportedly remove needles and syringes from dumps. Finally, during transport to dump sites, infectious waste or sharp materials can spill onto public roads.

1.4 Externality

Economists commonly use the term externality to refer to a situation where the actions of a certain individual or a group (an economic unit--may be a firm or a consumer) result in certain unwanted effects on others for which the individual or the group do not pay. Externalities, sometimes also called "external diseconomies" may arise whenever the market forces alone are insufficient to make an individual bear all the costs of his actions. Externalities are not socially desirable because their presence is likely to cause misallocation of resources. For example pollution of land, water, and air resulting from waste disposal and other associated activities is an externality. Hospital solid waste cause externalities through pollution and safety hazards.

Complete elimination of externalities may be impossible for that might mean cessation of certain activities essential to society. In dealing with externalities the aim is to find some means to manage economic activities to provide maximum public benefit. Economists have long recognized the need for public regulation of economic activities resulting in externalities.

Economists suggest a number of alternative ways to deal with externalities:

(i) Agreement: The unit generating externalities reaches an agreement, perhaps financial, with the recipients. This approach is feasible if the recipients of the externalities are identifiable and the effects are measurable. However, in the case of hospital solid waste disposal, one can neither identify all the affected individuals nor measure the externality effects.

(ii) Enlargement of the Economic Unit: In this approach, the economic unit is enlarged to become the recipient of its own externalities, thereby internalizing the externalities. Internalization of hospital externalities will require a change in the attitude of hospital authorities so that their decisions are based on an area wide point of view which considers the impact of their decisions on the total community.

(iii) Effluent Fees: This widely discussed approach, advanced by economists in the case of environmental pollution,suggests imposing appropriate effluent fees on the polluters and relying on market mechanisms to achieve reduced levels of pollution. Advantages include flexibility and continuous provision of incentives to polluters for minimizing pollution. Of the arguments offered against this approach, the most compelling is the difficulty in determining the appropriate fees.

(iv) Direct Governmental Intervention Through Regulations: This approach, generally followed at present to control environmental pollution, consists of regulating the operations at the sources of pollution in accordance with certain prescribed requirements. In some cases polluters may receive certain tax benefits as added incentives to minimize pollution.

Until recently hospitals have been more or less immune to most of the community regulations with little conscious consideration directed at the externalities which result from waste handling operations in hospitals. As a result, the social costs associated with these externalities have not influenced decisions for selecting waste handling systems or operational procedures.

The cost actually incurred by hospitals for waste handling operations, hereafter called "operational cost", will depend on the extent to which various externalities are permitted, thus directly influencing the selection and operation of the waste handling systems. If hospitals do not have to bear any responsibility for the externalities caused by the waste handling operations, management of each hospital will choose the least expensive waste handling system which complies with its own minimal internal standards. If, on the other hand, hospitals are not allowed to generate any externality, the operational cost of waste handling systems would be much more expensive so each hospital will then choose the least expensive waste handling system which does not generate any externality.

From an overall perspective neither alternative is as satisfactory as a third approach that compromises those two extremes. That is, if a hospital could estimate both the social costs of its externalities and the operational costs for different waste handling systems, then management could choose the most economical system on the basis of the combined total cost. These two costs are represented by the curves SC and OC, respectively, shown in Figure 1.1 where the abcissa represents various systems ranked in the order of decreasing externalities. The combined cost (SC + OC) is represented by the curve TC. The combined minimum cost corresponds to a system which generates externalities at a level P, an optimal level up to which attempts may be made to reduce the externalities by improving hospital solid waste disposal operations.

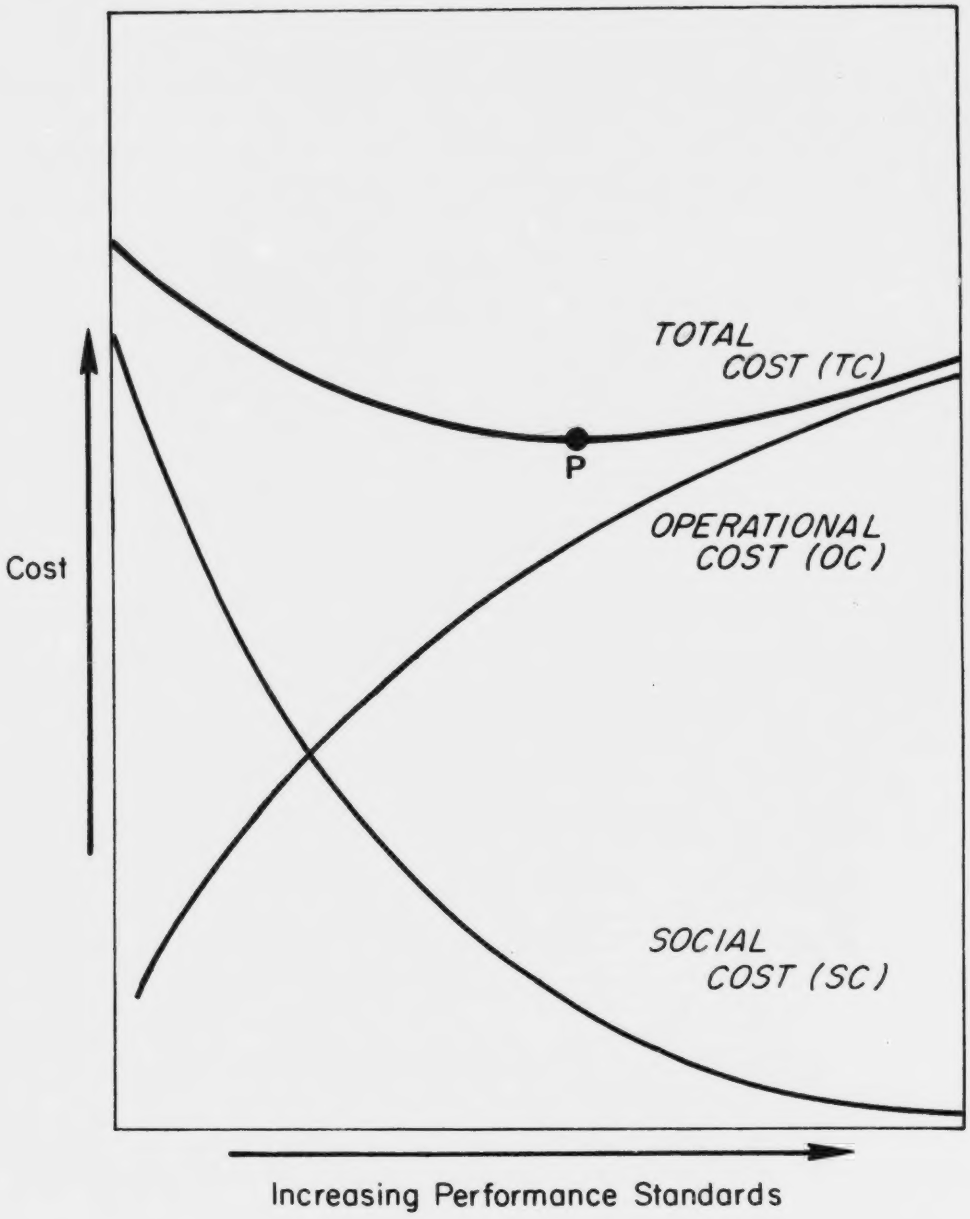

Figure I.1 Optimality required from a total cost point of view.

If hospitals are allowed to generate any externalities but forced to pay associated social costs, each hospital will choose a system corresponding to the level P of externalities. In fact, this approach is synonymous with the effluent fee scheme described earlier where polluters are charged effluent fees corresponding to the associated social costs.

Yet that system still is not practicable because regulatory agencies do not have the quantitative data necessary to determine the steady state conditions of environments. Yet that knowledge is a prerequisite in defining policies which will make appropriate trade-offs between air, water, and land pollution. What's more, this lack of knowledge hinders the quantification of social costs and, consequently, the determination of point P at this stage.

A more practical approach at present is for the regulatory agency to prescribe certain admittedly arbitrary exogenous standards for waste handling and require that hospitals operate their systems according to the standards. Regulations banning open dumping and open burning, prescribing limits on incineration emissions, and requiring that landfills follow specified operational procedures are examples of exogenous standards. Hopefully hospital administrators will make decisions about waste handling systems to achieve these standards, yet in the most economical way possible.

1.5 Internal Considerations in Hospital Solid Waste Handling

In addition to these externality problems, the environmental health and safety implications of waste handling also concern the hospital community and demand certain minimal performance standards in the hospital's waste handling operations. The potential contamination of the hospital environment from infectious waste poses the question of the welfare of patients, hospital staff, and visitors. The noise, vibration, congestion, and unsanitary conditions resulting from waste handling operations may cause inconvenience and discomfort to the hospital community. In addition, the fire hazards and potential physical injury to waste handling personnel are other important considerations which are too frequently ignored.

1.6 Rationale for Choosing Waste Handling Systems

The hospital management should make decisions about waste handling from a total system perspective which considers both the hospital and the host community. Regulatory agencies can force hospital management to take a macro viewpoint by setting compulsory standards prohibiting externalities exceeding certain levels. Similarly, the hospitals or the hospital regulating agencies should set appropriate internal standards for waste handling on hospital premises. Then the hospital will try to minimize the annual equivalent cost* of its waste handling operations within the scope of alternative designs that comply with the prescribed internal and external standards for waste handling. Minimization of the cost approach within the acceptable design alternatives can be accomplished through a cost benefit approach which avoids the controversy of pricing the benefits. Actually, the cost approach does not avoid the problem of pricing the benefits, but rather does not explicitly include pricing in the formulation. As formulated, the problem consists of two stages: The first stage deals with the derivation of the acceptable internal and external standards, tackling the controversial and difficult problems of identifying and measuring social costs and benefits. The second stage deals with the selection of a design which minimizes the total annual equivalent cost of waste handling operations, yet complies with the standards prescribed in the first stage.

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*The annual equivalent cost is defined as the uniform annual cost having the same present worth as the present worth of the initial cost and operating costs over the optimal life of the system based on an appropriate discounting rate.

The present study assumes that the prescribed standards are given and concentrates on the selection of optimal designs.

1.7 Integrated Approach to Optimal Selection of a Waste Handling System

An integrated approach, necessary for optimal selection of a waste handling system, requires a high level of planning activity where decisions are made from the viewpoint of the total system rather than of restricted microcontext of individual pieces of equipment, techniques, or methods. A total system encompasses the complete handling, processing, and disposal of hospital solid waste from the point of generation to the point of final disposal, considering the impact of these activities both inside and outside the hospital premises.

Key steps in the decision process of an integrated approach are:

(i) Identifying the functions (stages) involved in a complete waste handling system.

(ii) Indentifying various available alternative systems to accomplish different waste handling functions.

(iii) a. Defining a suitable set of waste categories for all the waste handling stages identified in (i). This involves the appropriate categorization of waste at each stage from a total system perspective.

b. Estimating the quantity of total waste and quantities for each category of waste.

(iv) Developing cost functions which will be used 1) to evaluate flow cost for different categories of the waste through different routes and 2) to compute the total cost. These cost functions based on internal and external standards, will relate the costs of alternate systems to appropriate hospital parameters, directly or through intermediate parameters.

(v) Evaluating the various composite systems and selecting an optimal system.

The problem can be formulated mathematically as follows:

Let S = number of distinctive stages (functions) into which the activities of a complete hospital solid waste system can be divided.

i = index of stage of waste handling.

A_i = set of waste categories handled at stage i.

J_i = index of category of waste handled at stage$_i$

C = cost function.

Then the problem is to choose a set of processes at each stage to minimize

$$C = \Sigma_{i=1}^{S} \quad \Sigma_{J_i \epsilon A_i} C_{iJ_i}$$

where C_{iJ_i} is the cost of handling J_ith category of waste, yet still meet prescribed internal and external standards.

The rest of this chapter deals with the first two steps, identifying functions and various available systems. Chapter II briefly describes various waste handling systems. Chapter III elaborates on the classification and quantification of waste. The cost functions developed in Chapter IV are based on prescribed standards given under "Operation Guidelines" in Appendix H. Chapter V uses reduced cost functions to compare different systems. Chapter VI discusses economies achieved by centralizing certain waste handling functions for a group of hospitals.

1.7.1 The Decision Tree and its Application to the Selection of Hospital Solid Waste Handling Systems

A decision tree is composed of a sequence of nodes representing decision points with a number of branches coming out of these nodes to represent alternatives available at that point. Figure 1.2 shows two simple decision trees.

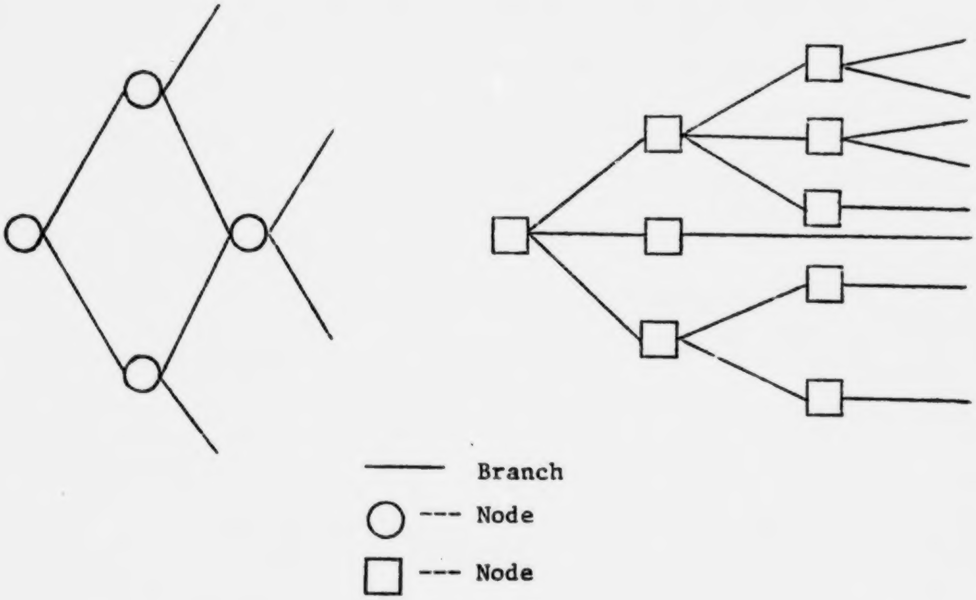

FIGURE 1.2

This approach provides a very valuable tool in decision making, especially when the decision maker faces a multiplicity of alternatives compounded further by uncertainties. The decision tree serves as a framework for a coordinated approach to decision making because at any stage decisions are made while considering their implications for the total system. Such a framework clearly brings out the compatibility and the non-compatibility of decisions at different stages under varying environmental conditions. Furthermore, the tree prevents the decision-maker from selecting any alternatives based only on local considerations instead forcing him to make decisions on an aggregate basis.

A decision tree for solid waste handling in hospitals will depict the stages and available alternatives for a complete waste handling system. Each node of this tree will denote some decision point during the flow of waste, and the branches coming out of each node will represent the available alternatives at that decision point. Identification of the decision points and the available alternatives at each node are critical steps in the development of a decision tree as earlier described in steps i and ii, and requires an up-to-date assessment of available technology.

The functions involved in a waste handling system are broadly classified as:

(i) Collection of waste from the points of generation, followed by transportation to some central point(s) within the hospital building-complex;

(ii) Treatment of waste on the hospital premises;

(iii) Transfer of waste from the hospital premises; and

(iv) Final processing and disposal of waste.

These four functions constitute the four stages of the decision tree shown in Figure 1.3. Decision stage 1 is concerned with the collection and transportation of the waste within the hospital; decision stage 2 with the type of treatment to be given to the waste on the hospital premises; decision stage 3 with the selection of a site where the waste (treated or untreated) would be transported for final treatment and disposal; and decision stage 4 with the choice of a transportation mode to transfer the above waste to the site chosen in decision stage 3. Figure 1.4 elaborates on stage 1 of the decision tree dealing with the collection and transportation of waste within the hospital. Chapter II describes those alternative systems at stage 1 and succeeding stages.

The decision tree can be expanded further to show more details. In addition, if a certain category of waste required handling in part or exclusively through modes not shown in the tree of Figure 1.4., the tree can be augumented easily to include such modes.

Each path through the decision tree corresponds to one composite system for a category of waste. An appropriate composite system for a given situation would be selected by following the appropriate paths for the given categories of waste.

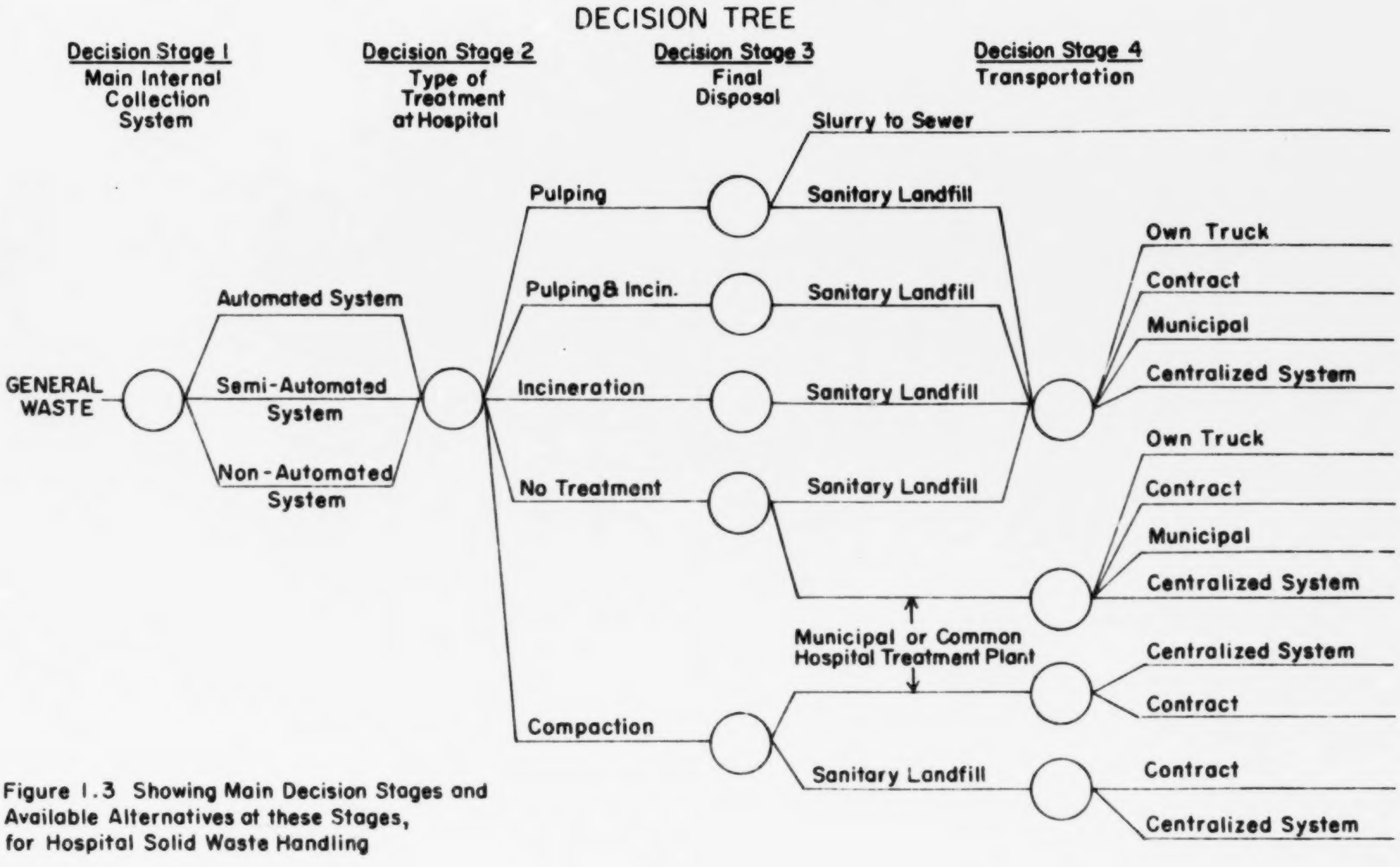
DECISION TREE
Decision Stage 1
Main Internal Collection System
Decision Stage 2
Type of Treatment at Hospital
Decision Stage 3
Final Disposal
Decision Stage 4
Transportation
GENERAL WASTE
Automated System
Semi-Automated System
Non-Automated System
Pulping
Pulping & Incin.
Incineration
No Treatment
Compaction
Slurry to Sewer
Sanitary Landfill
Sanitary Landfill
Sanitary Landfill
Sanitary Landfill
Municipal or Common Hospital Treatment Plant
Sanitary Landfill
Own Truck
Contract
Municipal
Centralized System
Own Truck
Contract
Municipal
Centralized System
Centralized System
Contract
Contract
Centralized System

Figure 1.3 Showing Main Decision Stages and Available Alternatives at these Stages, for Hospital Solid Waste Handling

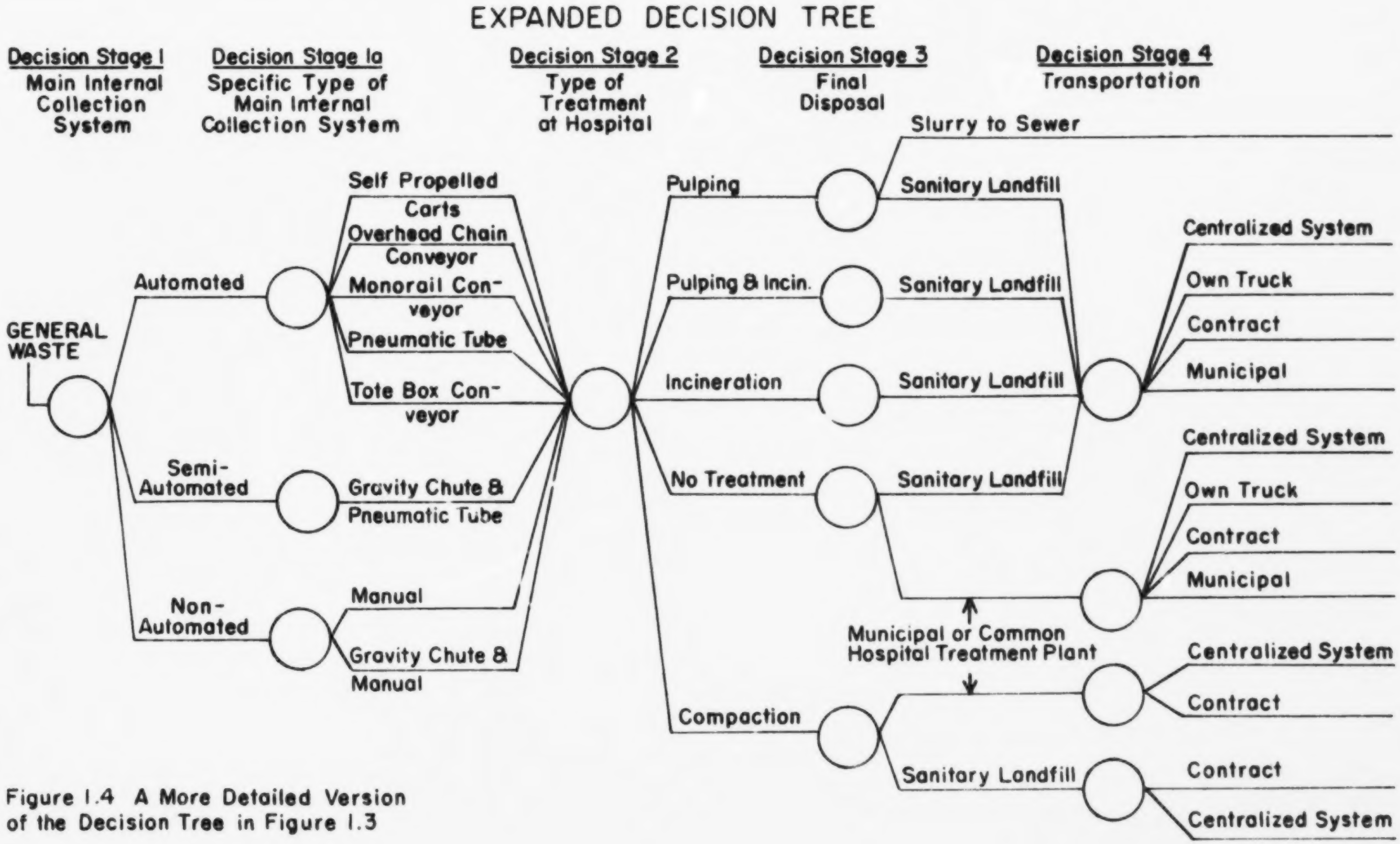
EXPANDED DECISION TREE
Decision Stage 1
Main Internal Collection System
Decision Stage 1a
Specific Type of Main Internal Collection System
Decision Stage 2
Type of Treatment at Hospital
Decision Stage 3
Final Disposal
Decision Stage 4
Transportation
GENERAL WASTE
Automated
Semi-Automated
Non-Automated
Self Propelled Carts
Overhead Chain Conveyor
Monorail Conveyor
Pneumatic Tube
Tote Box Conveyor
Gravity Chute & Pneumatic Tube
Manual
Gravity Chute & Manual
Pulping
Pulping & Incin.
Incineration
No Treatment
Compaction
Slurry to Sewer
Sanitary Landfill
Sanitary Landfill
Sanitary Landfill
Sanitary Landfill
Municipal or Common Hospital Treatment Plant
Sanitary Landfill
Centralized System
Own Truck
Contract
Municipal
Centralized System
Own Truck
Contract
Municipal
Centralized System
Contract
Contract
Centralized System

Figure 1.4 A More Detailed Version of the Decision Tree in Figure 1.3

CHAPTER II

DESCRIPTION OF VARIOUS WASTE HANDLING SYSTEMS

2.1 Introduction

Chapter I identified the four main stages of the solid waste handling function: 1) waste collection within the hospital; 2) waste treatment on the hospital premises; 3) transportation of waste from hospital premises; and 4) final treatment and ultimate disposal. This chapter briefly describes the alternate waste handling systems available at these four stages as shown in the decision tree.

2.2 Collection of Waste Within Hospital

In-hospital waste handling includes waste collection from points of generation and transport to one or more central storage locations. The complete process of waste collection within the hospital can be divided into two stages:

1. Collection of waste from points of generation and transport to intermediate accumulation points. Most waste initially is deposited in small receptacles, identified in this study as "initial storage points", which are placed at the points of origin. In recent years most of these receptacles have been equipped with disposable plastic liners which facilitate containerization and more efficient transfer of waste.

At suitable intervals, the waste that has accumulated in these receptacles is transferred, usually by housekeeping personnel, to larger containers (hereafter referred to as "intermediate accumulation points") located in utility rooms, trash rooms, janitor's closet or similar storage areas. In some areas such as the kitchen, the initial storage points also serve as intermediate accumulation points.

2. Collection of waste from intermediate accumulation points and transport to one or more central storage locations. Alternate methods (systems) to collect and transport waste from intermediate accumulation points to central storage location(s) for further handling are: a) manual system, b) gravity chute - manual system, c) gravity chute - pneumatic tube system, d) pneumatic tube system, e) other automated systems.

2.2.1 Manual System

The manual system has been and is still the most common method employed for in-hospital waste collection using conventional push carts to manually transfer waste from intermediate accumulation points to central storage location(s). For example, a workman transfers waste bags into his cart from each intermediate accumulation point. When the cart is full, the workman wheels it to a central storage location where he transfers the bags to the waste storage facility. The workman repeats this process until the waste from all intermediate accumulation points has been picked up. Usually one workman is responsible for waste collection from a number of floors, but in some hospitals separate workmen are responsible for waste collection from each floor. Sometimes departmental personnel transfer the waste generated in certain departments to the central storage location.

Although the manual method of waste collection is very flexible and can be adapted for any type and amount of waste, this labor-oriented system is very slow, adds to traffic congestion, and can contaminate the hospital environment.

2.2.2 Gravity Chute - Manual System

This method employs gravity chutes for the vertical movement of waste. A gravity chute is a vertical tube, square or cylindrical, usually fabricated of stainless steel, aluminized steel, or aluminum. Although the chutes are available in varying cross-sectional dimensions and thicknesses, hospital chutes range from 16 to 30 inches in breadth. The tube can be equipped with a cleaning and sanitizing unit and/or sprinklers. Several types of ventilation designs are available for chutes, and the chute must have a fire resistant rating of 1 to 2 hours.

The tube, provided with an opening on each floor, can be fitted with different types of doors for receiving wastes. For example, bottom-hinged doors provide a receptacle to pour waste into. Side-hinged doors which provide a larger opening than the bottom-hinged doors, and top-hinged push-in type doors also are available. Foot operated doors allow personnel to use both hands to dump waste. To prevent backdraft, the doors can be interlocked so that only one door can be opened at a time. Top-hinged rubber baffles also help prevent backdrafts.

Personnel feed the waste from intermediate storage through the door on each floor. The waste can automatically be discharged into a cart located at the bottom of the chute or carts can be filled manually on demand. When the cart is full, personnel take the cart to the central storage location for waste transfer and then return the empty cart to the bottom of the chute. Arrangements can be made to send the waste directly from the bottom of the chute to a desired processing unit.

Advantages of the gravity chute are an accelerated collection rate, relieved congestion in elevators and corridors, and shorter intermediate waste storage on each floor. However, the potential for environmental contamination and fire hazards are major problems associated with the use of gravity chutes.

2.2.3 Gravity Chute - Pneumatic Tube System

This system, which can be adapted to almost any existing chute system, utilizes a gravity chute for vertical movement and a tube usually operated pneumatically, for horizontal movement of waste from the bottom of the chute. A high velocity suction blower develops negative pressure inside the pneumatic tube, and the resulting air stream drawn through the tube carries the waste at a very high speed to a collection hopper. The high velocity air stream is filtered before being exhausted to the atmosphere.

Two types of gravity chute-pneumatic tube (or gravity-vacuum) systems are available. In one type, the gravity chutes connect directly to the pneumatic tube and in order to obtain a sufficient air flow through the pneumatic tube, an air source must be provided at the bottom of each chute. This system can transport only one load at a time from a charging station, that is, before the system can accept another load, the first load must be transported to its destination. One advantage of the system is that both trash and linen can be transported through the same chute and pneumatic tube. A diverter valve, activated by pressing a button when a load is charged, automatically diverts the trash or linen to the appropriate collection point such as a laundry or a trash room. In addition, the interlocking of all charging doors is required to insure that only one load can be charged and transported at a time.

In the other type of system, a valve separates each gravity chute from a horizontal pneumatic tube, allowing waste accumulation in the vertical chute(s). The valves, arranged to open either on a controlled time sequence or on a demand basis using level indicators, open one at a time to deposit the accumulated waste into the air stream of the pneumatic tube. The waste from one chute must reach its destination before the next valve can open. A by-pass can be provided around a valve to maintain a slight negative pressure in the gravity chute. Separate vertical chutes and horizontal tubes are required to transport linen and trash through this type of gravity-pneumatic system. The station doors can be interlocked to allow opening only one door at a time.

2.2.4 Pneumatic Tube System

In the pneumatic tube system (or simply pneumatic system), both the vertical risers and horizontal runs are under negative pressure. A double door charging station is standard equipment with this system, completely eliminating danger of backdraft. The outer door opens to a receiving compartment which is separated from the negative pressure inside the tube by an inner door. After placing material to be transported in the receiving compartment, the workman activates the system by pushing a button. When the system is ready to receive the material, the inner door automatically opens, dropping the material into the high-velocity air stream which rapidly transports the material to its destination. The inner door then closes, and the system deactivates. The system will re-activate on a first-come-first-served basis or can be ordered in a desired sequence. Each station is equipped with a safety time cycle control to allow only one load of one type of material to be accepted by the pneumatic tube.

This system is very fast, allowing immediate removal of waste from the floors. Furthermore, the pneumatic tube system can handle both trash and linen through the same chute by using a diverter valve. However, this system is not recommended for the conveyance of infectious and pathological waste, radiological waste, or toxic chemical and flammable solvents.

2.2.5 Other Automated Systems

Other automated systems for movement of aggregated material such as solid waste usually are very expensive. The following systems are described briefly:

(i) self-propelled carts;
(ii) monorail conveyor;
(iii) overhead chain conveyor; and
(iv) tote box conveyor.

1. Self-Propelled Carts. This system features electric battery-powered carts which move horizontally on electronic paths provided by wires concealed in the floor and vertically through specially installed elevators. An operator dispatches carts from a central station by dialing the destination of each cart into its electronic memory system. Each cart then proceeds automatically through the corridors to the system elevator, and "calls" the elevator. When the elevator opens, the cart enters the elevator and directs it to the proper floor, exits,

and moves to its assigned destination. The cart can be programmed for one or a series of destinations, and will either restart automatically after each stop of a predetermined length of time or can be started manually at a desired time. Manual control allows the removal of the cart from its path. After supplies are removed from the cart the empty or re-supplied cart is directed back to the central station or any other desired destination. When the cart reaches the central station, the dirty supplies are taken off; then the cart is washed and sterilized, ready to be re-loaded.

The interior of the cart can be adjusted to provide large bins for linens or partitioned and shelved to provide space for individual trays. The enclosed cart completely encapsulates its load, eliminating the need for separate routes for soiled material. The cart will stop automatically if confronted with an obstacle; however, this safety feature can be a disadvantage greatly slowing down the transport process if the obstacle is not removed quickly.

2. Monorail Conveyor. In a typical monorail conveyor system, self-propelled transporters carried on monorail tracks usually operate within their own shaft and tunnels, except for injection and ejection at the various stations in the system. Each transporter, suspended from the monorail, carries carts containing up to 500 pounds of the materials and supplies to be moved. Two small motors provide adequate motive power to each transport. While in motion the carts ride several inches off the floor. The system operates automatically except during loading and unloading of the carts. Each station is equipped with a control panel for summoning or dispatching transporters, although the

destination of a transporter can be programmed on the transporter itself. The system is designed with a container wash and storage area to keep a supply of sanitized containers available to all users. Carts carrying soiled supplies pass through a washer sterilizer unit after supplies are taken off the cart.

3. Over-Head Chain Conveyor. Whereas the transporters of a monorail conveyor system are individually equipped with motors, the overhead chain conveyor system uses overhead tracks for the motive power to move transporters or trolley carriers of the loaded carts. One system of this type features a semi-enclosed power chain composed of a series of vertical and horizontal roller wheels operating on the bottom and sides of the enclosing channel. A cart can be programmed to automatically reach its destination. When the cart reaches its destination, it is automatically shunted off the main-line for manual detachment from the trolley and transfer to the desired location. As in the monorail system, each cart is cleaned after being used to carry soiled supplies.

4. Tote-Box Conveyor. Tote boxes containing materials to be transported are moved vertically and horizontally on roller conveyors powered by an endless belt, by a continuous chain, or by a series of progressive chains. Tote boxes carrying supplies are dispatched from any station to any other station. Destinations, usually programmed on the boxes, are "read" magnetically by the system or by reflective light. The boxes for hospital use can be sterilized and are tapered for nesting, usual sizes for hospital use are 16" x 20" x 10" high or 16" x 22" x 8.5". Box dividers and spacers can be provided for bottles

and similar items to avoid spilling and tipping.

2.3 Treatment of Waste on Hospital Premises

This stage deals with the treatment the waste should receive on the hospital premises before leaving the hospital for ultimate disposal and includes the following practices: no treatment, incineration, pulping, compaction, combined pulping and incineration.

2.3.1 No Treatment

Under this option the waste is hauled from hospitals without any treatment. This is the oldest and simplest way of removing waste from hospitals, but not necessarily the best way from an overall point of view.

2.3.2 Incineration

Incineration greatly reduces the volume of the waste to an inert residue by burning at high temperatures. Some authors consider incineration the only logical process for treating solid waste in general, as well as one of the most effective ways for treating hospital waste. However, incineration also is considered a significant source of air pollution and so has been severely attacked by regulatory agencies responsible for air pollution control. These agencies have formulated very strict standards limiting emissions from incinerators and demanding significant improvement in both equipment design and operation of incinerators. Older incinerator models may be equipped with a variety of control devices which help curb the emission of air pollutants, but such improvements may not be feasible, mechanically or economically.

Incinerators, manufactured in various sizes, can be installed either inside or outside the hospital. Optional devices to automatically feed waste into the incinerator provide both better control over the incineration process and improved safety to operating personnel. Special types of incinerators are available for burning pathological and infectious waste. To economize on waste handling expense, a cluster of hospitals can share a large size incinerator. The inert residue or ashes left after incineration, removed automatically or manually, usually are hauled to a landfill.

2.3.3 Pulping

Pulping employs the principles of mechanical and hydraulic shearing to reduce waste into a pulp. Although pulping reduces waste volume, the addition of water greatly increases the weight of the waste. The liquid pulp either can be discharged through the sewer system or squeezed to extract water, producing a semi-dry pulp which is hauled to a landfill or, as recently attempted, burned in a specially designed incinerator.

In the pulper, water and waste first are introduced into a bowl with a rotor mounted in the bottom. The rotating propeller creates a hydraulic vortex, drawing the waste materials downward. The rotor and cutting devices tear up the waste, macerating the waste into a fine pulp or slurry. A deodorizer can be introduced into the pulper. The slurry passes out of the pulper through a perforated bed plate which restricts over-size particles and non-pulpable objects. A junk extractor automatically removes the non-pulpable objects. The slurry is pulped to an extractor which removes the water, recycling the water back into the pulper, and discharges the semi-dry pulp into a container.

The capacity of pulpers used in hospitals varies from 400-4000 pounds per hour. The pulpers can be located under gravity chutes and fed directly from the chutes.

2.3.4 Compaction

Compaction, a volume reducing process which does not change the weight of the waste, is completed in a compacting machine with an attached container that receives the compacted waste. In general, in-hospital compaction of waste can be conducted either at one central place using a large compactor or at suitable scattered locations (such as the kitchen, or bottom of the gravity chute) using smaller compactors. Waste compacted at scattered places may be contained in boxes or baled, then brought to a central collection point. Containers for compaction at a central location generally range from 10 cubic yards to 43 cubic yards in volume. Specially designed roll-off and roll-on trucks haul these containers to sanitary landfills.

The density of the compacted waste depends on the compaction ratio of the compactor used. Optional mechanisms can automatically feed waste to the compactor. Usually a sanitizer is added to the waste to minimize odor.

2.3.5 Pulping and Incineration

Incineration of pulped wastes offers another method of in-hospital waste treatment, yet the high moisture content of the pulp could make incineration difficult. On the other hand, the uniformity and small size of waste materials allows automatic feeding of pulp to incinerators at controlled rates so incineration can be regulated better.

2.4 Transportation of Waste from Hospital Premises

Treated and untreated waste is removed from hospitals for final treatment and/or ultimate disposal via the hospital's own trucks, the municipal collection service, private trucking contractors, or a cooperative hauling system shared by a number of hospitals.

2.4.1 Own Hauling

Hauling with the hospital's own trucks is becoming less common as in-hospital compaction becomes more popular because the special truck required to transfer waste compacted in a large container is economically unfeasible for most hospitals.

2.4.2 Municipal Service

Some municipalities provide hauling services for commercial and institutional, as well as residential, waste. The waste is usually collected in a rear end loader truck, which compacts the waste as it is fed to the rear of the truck. Although some municipalities provide waste collection as a municipal tax supported service, others charge according to a pre-determined weight or volume rate. Again, municipal hauling may not be available for waste compacted in large containers.

2.4.3 Private Contract

Today most hospitals contract with private haulers for waste pickup at regular intervals. Rates might be a flat monthly amount or charged according to the amount of waste hauled daily. Private contractors use both rear end loaders and front end loaders for hauling waste. Each hospital must provide for on-site storage space prior to collection by the contractor.

2.4.4 Cooperative Hauling

Several hospitals in an area can use a single system on a cooperative basis. Although all types of waste can be handled more economically this way, cooperative hauling is suitable only if several hospitals are located in close geographic proximity to each other.

CHAPTER III

CLASSIFICATION AND QUANTIFICATION OF WASTE

Chapter I identified waste handling as a flow problem of different waste categories through a network where the selection of paths for the different waste categories was based on minimizing the total cost while maintaining certain minimum specified standards. This chapter considers the problem of developing a suitable scheme for waste classification and for estimating the quantities of the various categories.

3.1 Classification

Solid waste generated from hospitals comprises many materials having diverse characteristics which affect the suitability of various methods of waste handling. An economic system of waste handling first requires classification of hospital waste which considers the effectiveness and economics of alternative waste handling methods at different stages for different types of waste. If all types of waste were handled the same way,the total cost including both the labelled and unlabelled costs may be more than the cost of a system which appropriately treats the different categories of waste.

Appendix B summarizes several classification schemes for hospital solid waste proposed in the literature. However, these classification schemes lack economic motivations, disregarding the suitability of the different waste handling and disposal techniques for each category. As long as quantitative data are unavailable on the effectiveness and economics of different waste handling systems for each type of waste, controversies can be expected over any classification scheme. This paper will identify important attributes associated with hospital solid waste, then use those attributes to develop a classification system. Such a scheme allows aggregation of different kinds of waste into flexible categories.

Important attributes which can be associated with hospital waste include: burnable (B), non-burnable (N-B); infectious (I), non-infectious (N-I); grindable (G), non-grindable (N-G); radioactive (R), and non-radioactive (N-R). Figure 3.1 displays these in the form of a tree. Additional important attributes can be included in the tree. When all the attributes are included, the total waste is divided into k distinctive types of waste, one corresponding to each terminal node of the tree. The major problem of categorization is lumping the distinctive types of waste into suitable categories determined by the economics and effectiveness of different waste handling systems.

If $p_1, p_2, \ldots, p_k$ denote the percentages of the k distinctive types which are to be grouped into s categories, and U_j denotes the percentages of the jth category, then

$$U_j = \sum_{i \epsilon A_j} p_i \qquad j = 1,2, \ldots, s$$

where A_j is the set of distinctive types to be lumped in the jth category. The value of s may differ at the various stages of waste handling.

The classification and quantification of waste simplifies the consideration of the following three problems:

(i) Determination of s at various stages of waste handling;

(ii) Estimating the total quantity Q of waste; and

(iii) Estimating the U_j's for the s categories which, multiplied by Q,

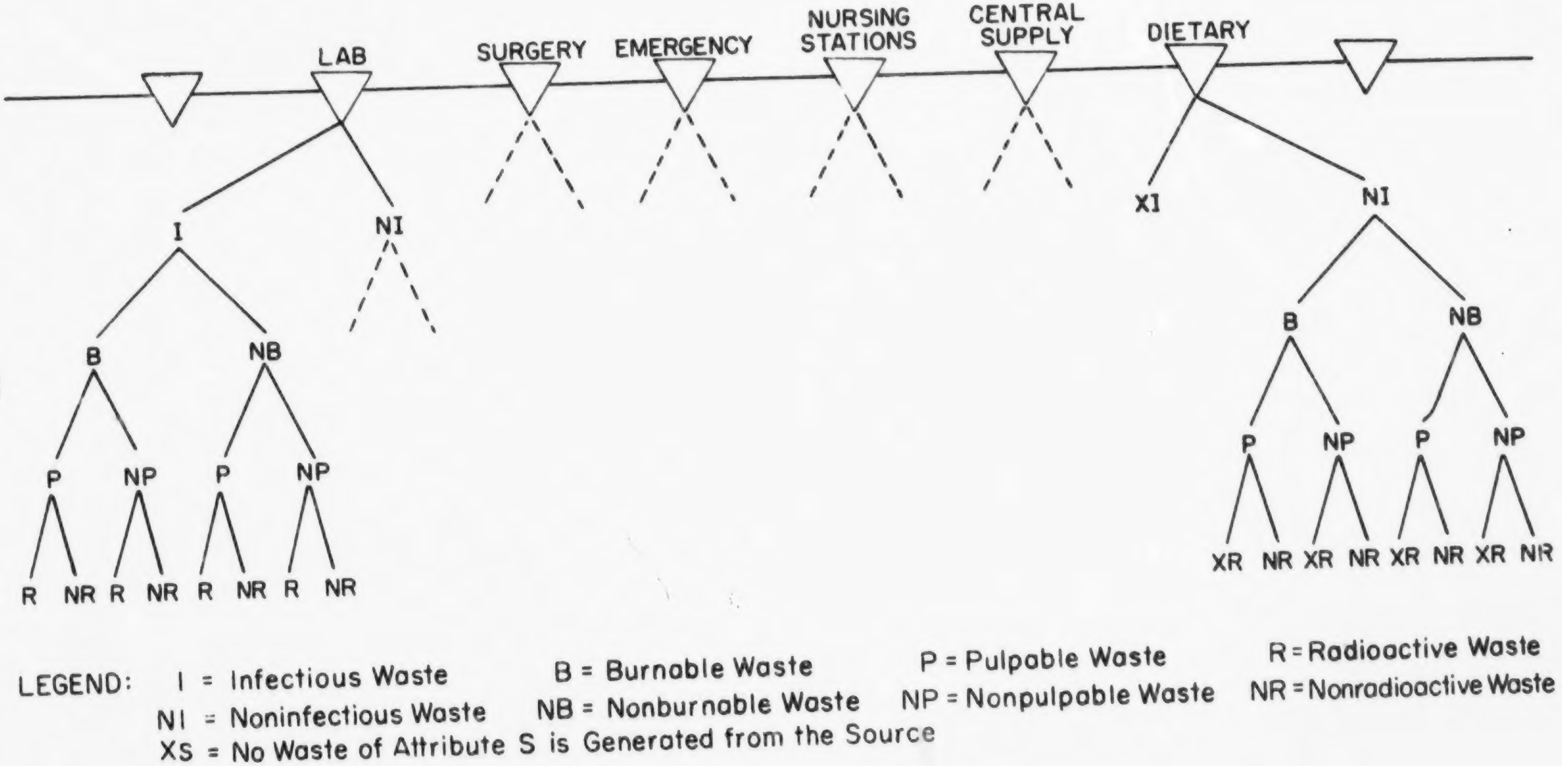
NURSING STATIONS
CENTRAL SUPPLY
LAB
SURGERY
EMERGENCY
DIETARY
I
NI
XI
NI
B
NB
B
NB
P
NP
P
NP
P
NP
P
NP
R NR R NR R NR R NR
XR NR XR NR XR NR XR NR
LEGEND: I = Infectious Waste
NI = Noninfectious Waste
XS = No Waste of Attribute S is Generated from the Source
B = Burnable Waste
NB = Nonburnable Waste
P = Pulpable Waste
NP = Nonpulpable Waste
R = Radioactive Waste
NR = Nonradioactive Waste

Figure 3.1 Classification of Waste by Attributes

will give the estimated quantities of each of the s categories.

This study adopts the following classification in the evaluation of various waste handling systems. For the collection stage, the waste is divided into infectious and non-infectious categories; for the treatment stage, the non-infectious waste is further divided either in burnable and non-burnable categories or in grindable and non-grindable categories; and, for the transport and ultimate disposal stage, into infectious and non-infectious. This classification is arbitrary because data on many aspects are lacking so the optimal classification can not be developed. Because the small quantity of radioactive waste is of a very specialized nature and requires special handling procedures, this study will not consider radioactive waste.

3.2 Quantification

In this section regression analysis is used to develop estimates of the total amount Q of waste generated in pounds per day from hospitals as a function of the pertinent hospital parameters. The U_j's have been estimated separately using the data available from different sources.

3.2.1 Earlier Studies on the Amount of Solid Waste Generated from Hospitals

The literature contains several studies estimating the amount of solid waste generated by hospitals usually determined as the amount of waste generated in pounds per day per patient or pounds per day per bed. Appendix A summarizes the estimates given in those studies. The estimates in most of the reports usually are simple estimates of data collected through questionnaires or by direct observations, usually from small samples. Two of the studies,[18,31] one by the American Public Health Association (APHA) and the other by Iglar and Bond, are broader in the extent of their surveys. The APHA study, basing its estimates on questionnaires returned from 29 hospitals, suggested expressing waste in terms of the hospital "Equivalent Population"* in an attempt to include the doctors, nurses and other staff with the patients. The study by Iglar and Bond [18] derived several equations through regression analysis which related the amount of waste generated from hospitals to different parameters.

These studies show wide variation in estimates of the amount of solid waste generated by hospitals possibly the result of one or more of the following:

(i) Non-Standarization. Some reports included the new-born bassinets and the new-born census in the ttoal number of beds and patient census, respectively, whereas others did not.

(ii) Varying Use of Single-Use Items. The varying use of single-use items greatly affects the amount of waste generated, yet none of these reports has explicitly accounted for this factor.

(iii) Presence of Certain Services in the Hospitals. The presence of certain services such as computer data processing could cause a substantial difference in the amount of waste generated. No adjustment has been made for such services.

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*"Equivalent Population" was defined as "total patients plus staff members in full time residence plus the balance of total number of employees multiplied by an assumed factor." A proposed factor was 5/21.

(iv) Type of Hospitals. Iglar and Bond[18] showed that teaching and research hospitals generate significantly higher amounts of waste per day per patient than non-teaching and non-research (general) hospitals. They also showed that the hospitals located in SMSA* generate more waste than the hospitals not located in SMSA. In spite of these two recognized differences all the hospitals were lumped together in the regressions. This study will make adjustments for those differences.

3.2.2 Present Study on the Amount of Waste Generated from Hospitals

The analysis in this study attempted to reduce the variability of the estimates by stratifying the hospitals, then performing separate regression analyses for each type further refined by explicit adjustments according to the varying use of disposables and the presence or absence of a computer data center.

3.2.3 Description of Data for the Present Study

Since the quantity analysis in this study uses the data from the study by Iglar and Bond, this section will describe briefly how they collected the data. Based on a pilot study of 14 hospitals they estimated that a sample of approximately 100 hospitals would give estimates of the weights of different types of waste within plus or minus 10 percent accuracy. Therefore, 105 hospitals were chosen randomly across the nation, and personal visits were made to those hospitals. The quantities of waste from hospitals were measured directly and the data were recorded on specially designed survey forms.

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*Standard Metropolitan Statistical Area (SMSA) was defined for census purposes as "essentially an area including one city with 50,000 inhabitants or more, or under certain conditions, two cities with this population combined together with contiguous metropolitan counties having economic and social relation to the city."

To carry out the analysis in this study, questionnaires were sent to all of the 89 general hospitals included in the original sample of Iglar and Bond. This questionnaire sought information on the use of disposables, computer services, the number of meals served per day, and the number of trainees in the nursing school - all retroactive to the time of the Bond and Iglar survey. Forty-seven of the 89 hospitals returned completed questionnaires. The present analysis is based on the adjusted data from the above 47 hospitals, 25 being in SMSA and 22 not in SMSA. A summary of the questionnaire is given in Appendix C.

3.2.4 Adjustment of the Data for the Present Study

The following adjustments were made in the data collected by Iglar and Bond on the amount of waste.

1. Adjustment of the Data for the Use of Disposable Items. The level of use of disposable items is the factor that stands out most prominently as influencing the quantity of waste. The emerging trend towards use of disposables in medical facilities reached a noticeable level in the 1950's when items such as paper bath mats, plastic petri plates, and plastic receptacle liners became available. A steep increase in the adoption of disposables began in the early 1960's with the introduction of such single-use items as masks, gloves, syringes, surgical drapes, and several other large volume items. This increase has continued as more and more disposable patient-care, laboratory, dietary, and housekeeping items become available on the market. In 1966

Michaelsen and Vesley[23] listed more than 125 single-use items in use at that time just for nursing services. By now (1972) that number has multiplied many times. Studies indicate that the use of disposables will increase further in the coming years. Another study[7] predicts the estimated sale of all disposable hospital supplies in the U.S.A. will reach 900 million dollars by 1978, a significant increase compared with the sale figure of 246 million dollars in 1968.

In certain hospitals the high usage of disposables has already made solid waste handling a critical problem. One hospital administrator[25] recently commented that the "breaking point for his institution has been the use of disposable patient trays." Patient safety has been cited as the prime reason for the increasing use of disposables, yet a large-scale switch to the use of disposables could lead to many-fold increases in the amount of waste generated from a hospital. Assigning a dollar value to the benefits accrued from the use of disposables is difficult, yet increased cost is an unavoidable fact of large scale use of disposables.[14]

Very little work has been done to quantify the additional amount of waste associated with the usage of disposables. Holbrook[16] reported that at one hospital, waste generation jumped from 9 to 19 pounds per patient per day over a period of 11 years, an increase he attributed mainly to the increasing use of disposables. Single Service Institute Study[30] of a hospital in 1970 estimated an increase of 19 ounces per day per patient in waste generation if all the food service items were changed to disposables. The Plate, Cup and Container Institute Inc.[27] estimated that a similar conversion will increase waste about 1.5 pounds per day per patient. According to rough estimates, converting from regular to disposable linen will increase the weight of waste by 1/3 to 1/2.

A more comprehensive quantitative study was needed to obtain better estimates. This study categorized all single-use items in five major groups: food service items, linen, surgical items, laboratory items, and patient care items. Tables 3.1, 3.2, and 3.3 estimate the contributions to solid waste from disposables in the first three groups based on data collected at different hospitals during actual observation of the number of items used and the unit weight of these items. Some data on the unit weights was supplemented from the suppliers' catalogues. However, no explicit adjustment was made for the disposables in the last two groups. The use of disposable laboratory items was observed to be fairly common, and of similar magnitude in hospitals in the sample. Moreover, disposable laboratory items contribute relatively little to the amount of solid waste, so the analysis would not be significantly improved by making adjustments for varying use of disposables in this group. Although the use of disposable patient care items can contribute considerably to the amount of waste, that waste is of a very specialized nature because certain items are used only for a particular type of patient. Many items in the patient care-kit (which shows a little more uniformity in its usage) can be taken home by the patients, and some of the items end up as a liquid waste. Therefore any purposeful adjustment is very difficult.

In the present analysis, the weights of solid waste used in regression analysis by Iglar and Bond were adjusted for the varying use of disposables. From Tables 3.1, 3.2 and 3.3 on unit weight contributions plus the questionnaire results on the use of disposables, the amount of solid waste associated with the use of disposables was estimated for every hospital, then subtracted from the original amount* of waste reported from that hospital. Consequently, the adjusted data represent the amount of waste generated from hospitals exclusive of disposables.

2. Adjustment for the Use of Computer Services. Computer facilities in hospitals have greatly increased during the last five years, and this trend continues. Yet computer data centers generate a significant amount of solid waste. Observations made in different hospitals showed that hospitals installing computer facilities utilize them for billing the patients, tabulating statistics for use in administration, taking inventory, and other purposes. Relating the amount of waste generated from the computer data center to the average number of patients arrives at the estimate of 0.5 pounds per patient per day. The weights of solid waste determined after adjustments for the varying use of disposables were further reduced on the basis of this estimate.

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*At many hospitals it was not possible to measure directly the amount of waste going through the grinders and discharged to the sewerage system, mostly for food waste grinders. Estimates of quantity of waste going through the grinding units were derived by computing weights of garbage found in a few instances where it was possible to weight the garbage sent to the grinders. Two cases were distinguished: 1) grinders used for both dishwashing and food preparation, and 2) for dishwashing only. The estimates for these two cases for the garbage sent through the grinders were respectively 2.5 pounds and 1.7 pounds per day per patient. The waste quantities associated with these activities were added to the other weights of waste measured from the hospitals to obtain the weights of waste as used in the regression analysis.

TABLE 3.1

ADDITIONAL SOLID WASTE CONTRIBUTED PER PATIENT MEAL BY THE USE OF SINGLE-USE DIETARY ITEMS

Item	Consumption Per Day Per 3 Patient Meals	Dry Weight in Pounds	Percentage
Cutlery:			
Knives	3.0	.051	
Forks	3.0	.048	
Spoons	3.0	.042	
		.141	11%
Dishes:			
Plates: 9"	3.0	.102	
Plates: 6"	3.0	.069	
Cover for 9" plates	3.0	.198	
Cover for 6" plates	3.0	.132	
Bowl	3.0	.051	
Coffee mugs	3.0	.075	
Hot & cold mugs	3.0	.030	
		.657	53%
Tray & tray covers:			
Trays	3.0	.375	30%
Tray covers	3.0	.075	6%
		.450	36%
	TOTAL	1.25	

CONTRIBUTION PER PATIENT MEAL: .42 pounds

TABLE 3.2

ADDITIONAL SOLID WASTE CONTRIBUTED PER OCCUPIED PATIENT BED BY THE USE OF DISPOSABLE LINEN

Item	Items/day	Dry Weight in Pounds	Percentage
Sheets	2	.976	51%
Pillow cases	2	.212	11%
Wash cloths	2	.022	1%
Face towels	2	.065	3%
Gown	1	.313	16%
Draw sheet or spread	1	.338	18%
		1.926 ≈ 1.9 Pounds	

TABLE 3.3

ADDITIONAL SOLID WASTE CONTRIBUTED PER SURGICAL PROCEDURE BY THE USE OF SINGLE-USE SURGICAL ITEMS

(based on estimate of 7 persons present per operation)

Item	Items Per Surgical Procedure	Dry Weight in Pounds	Percentage
Large drapes	3	1.23	23%
Small drapes	2	0.20	
Towels	10	0.65	10%
Masks	7	0.105	2%
Caps	7	0.112	2%
Shoe covers	7 pair	0.42	7%
Gloves	7 pair	1.344	21%
Gowns	7	2.191	35%
		6.25 pounds	

Contribution per surgical operation: 6.25 pounds

3.2.5 Regression Analysis

The regression analysis in this section applies to general hospitals only. Separate analyses are made for hospitals located in SMSA and for hospitals not located in SMSA. The data collected by Iglar and Bond (adjusted for the use of disposables and computer facilities, as described in section 3.2.4,)were used in these analyses. In each case the regression analysis is aimed at relating the total amount of waste generated from hospitals in pounds per day (treated as the dependent variable) to some of the important hospital characteristics (treated as independent variables).

Notation:

y = weight of solid waste in pounds per day

x_1 = total hospital census, including newborn, on the day the survey was performed

x_2 = number of surgical operations* per year performed by a hospital

x_3 = number of out-patient visits+ per year

x_4 = total number of hospital employees

x_5 = number of nurses in the training school

x_6 = number of meals served on the day the survey was performed

N = sample size (number of hospitals)

Let:

$$y = a + a_1x_1 + a_2x_2 + a_3x_3 + \ . \ . \ . \ . \ a_6x_6 \qquad (1)$$

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*To be more correct and consistent, the number of surgical operations on the day of the survey should have been used. Due to the lack of such data, total annual operations were used.

+The same remark made about surgical operations, is also applicable here.

represent the equation to be estimated by the regression analysis. Let y' be the estimate of y and a', a_1', a_2', ... a_6' the sample estimates of a, a_1, a_2, ... a_6 respectively, with $S_{a'}$, $S_{a_1'}$, ... $S_{a_6'}$ as estimates of their corresponding standard deviations.

3.2.6 Results

1. For hospitals not in SMSA. The final regression equation derived in this case is:

$$y' = -56.4 + 5.85x_1 + .095x_2 \text{ (see Figure 3.2)} \qquad (2)$$

with multiple correlation coefficient (R) = .984

Where: $a' = -56.4$

$a_1' = 5.85$

$a_2' = .095$

and $S_{a'} = 20.6$

$S_{a_1'} = .58$

$S_{a_2'} = .02$

The standard deviation ($S_{y'}$) of $y' = \sqrt{S_{a'}^2 + S_{a_1'}^2 x_1^2 + S_{a_2'}^2 x_2^2}$

$$= \sqrt{424 + .336x_1^2 + .0004x_2^2}$$

2. For hospitals in SMSA.

$$y' = 19.5 + 8.5x_1 \text{ (see Figure 3.3)} \qquad (3)$$

with simple correlation coefficient (r) = .93

where: $a' = 19.5$

$a_1' = 8.5$

$S_{a'} = 82$

$S_{a_1'} = .70$

The regression coefficient a' was found insignificant when tested by

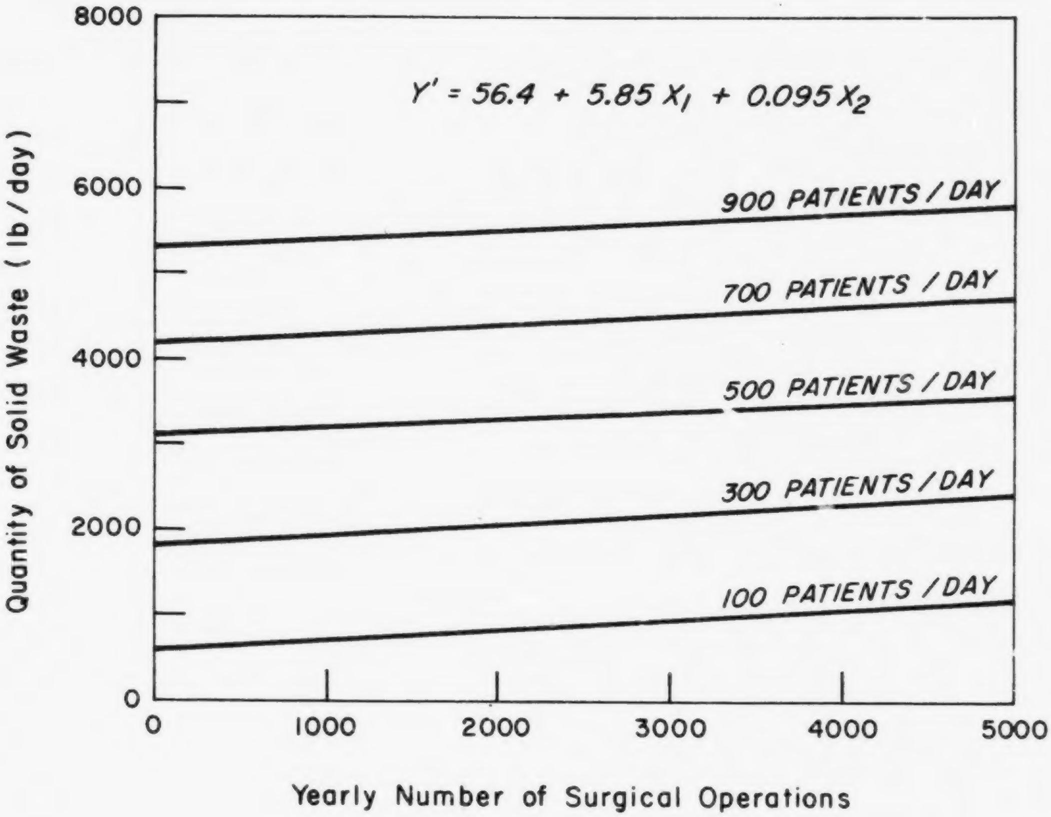

Figure 3.2 Showing quantity of solid waste (Y') generated in a hospital **not in** SMSA as a function of the number of surgical operations performed per year (X_2) and the daily hospital census, including newborn (X_1).

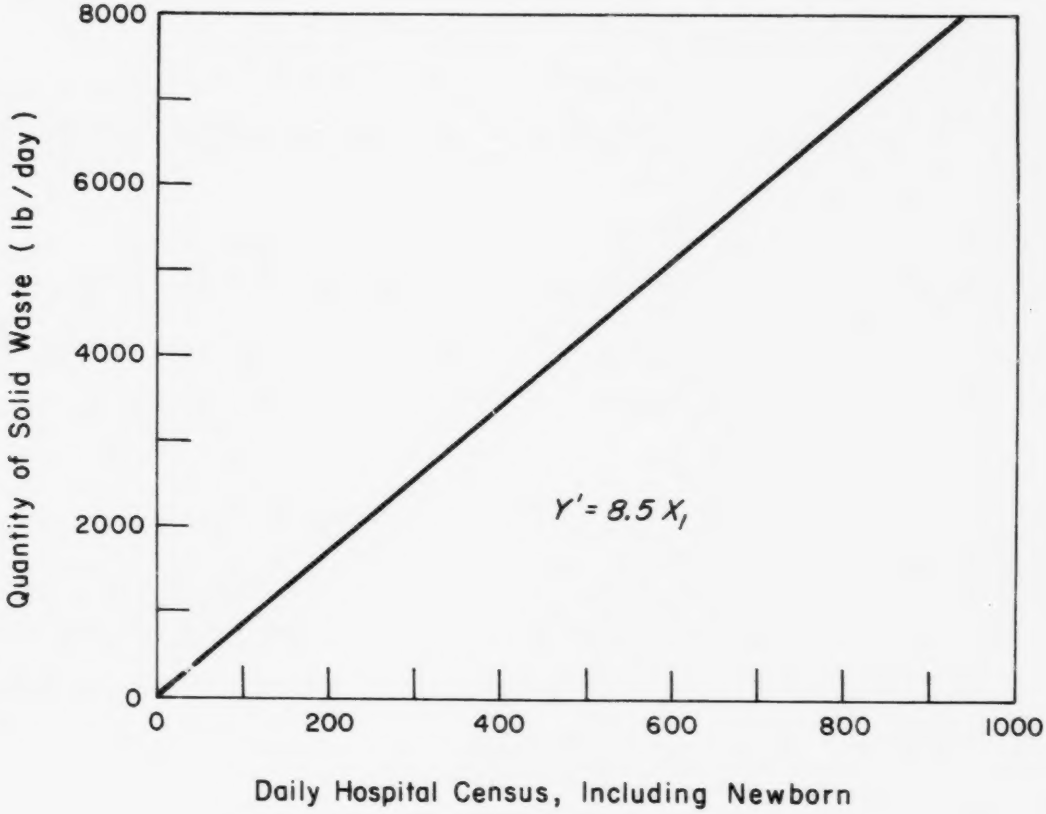

Figure 3.3 Showing quantity of solid waste (Y') generated in a hospital in SMSA as a function of daily hospital census, including newborn (X_1).

the t-test at a level $\sigma = 0.05$, so the equation (3) reduced to $y' = 8.5x_1$. Standard deviation ($S_{y'}$) of $y' = \sqrt{0.49x_1^2} = 0.7x_1$

A discussion of the regression procedures and analysis is given in Appendix D.

3.2.7 Adjustment of the Solid Waste Quantity Estimates to Include the Effects of the Use of Disposables and Computer Services

The data on the quantity of solid waste used in the regression analysis was adjusted to exclude the amount of solid waste generated by the use of computer services and certain disposables because of their varying use in hospitals.

The additional solid waste quantities generated per day by the use of all the disposable dietary and linen items listed in Tables 3.1 and 3.2 are 1.25 pounds per patient and 1.90 pounds per patient respectively. The use of computer services contributes an additional 0.05 pounds per patient per day. Together the use of computer services and all the disposable items contributes 3.2 pounds per patient per day.

Figure 3.4 shows the total additional solid waste generated per day by the use of disposable dietary and linen items and computer services as a function of the daily census and the actual pounds per patient contributed by the use of computer services and disposables for a particular hospital.

An additional 6.25 pounds is generated per surgical operation if all the disposable items listed in Table 3.3 are used. Figure 3.5 shows the total additional solid waste generated per day by the use of disposable surgical items as a function of the number of surgical operations performed per day and the actual quantity of disposable

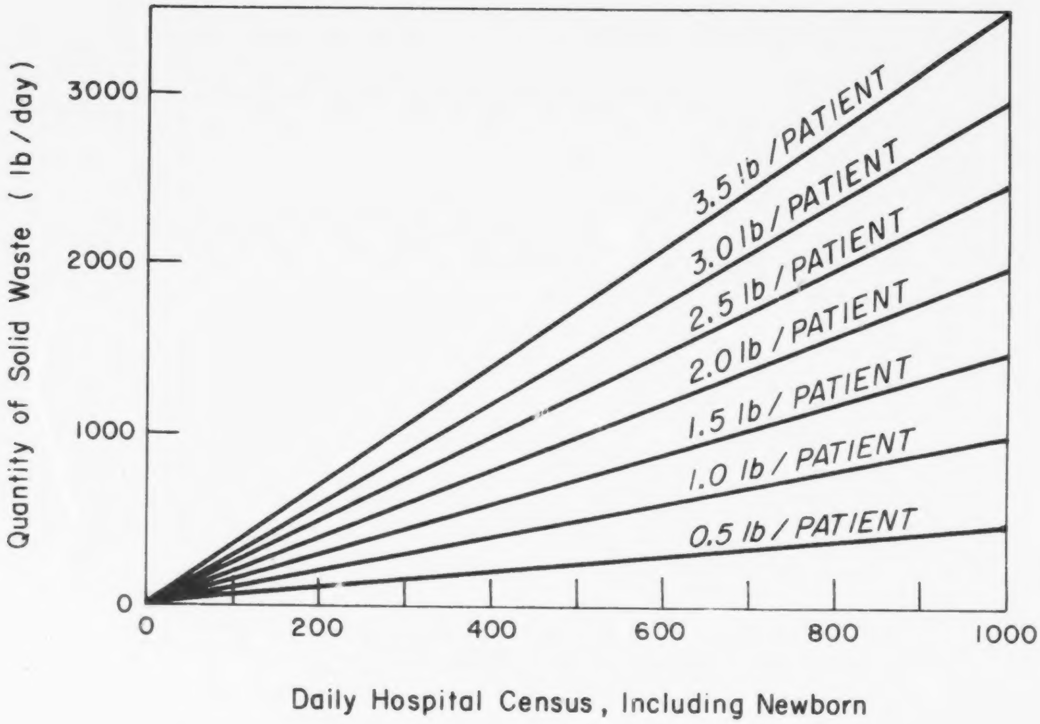

Figure 3.4 Showing additional quantity of solid waste generated per day by the use of computer services and disposable dietary and linen items as a function of the daily hospital census and the actual pounds per patient contributed by the use of computer services and disposables for a particular hospital.

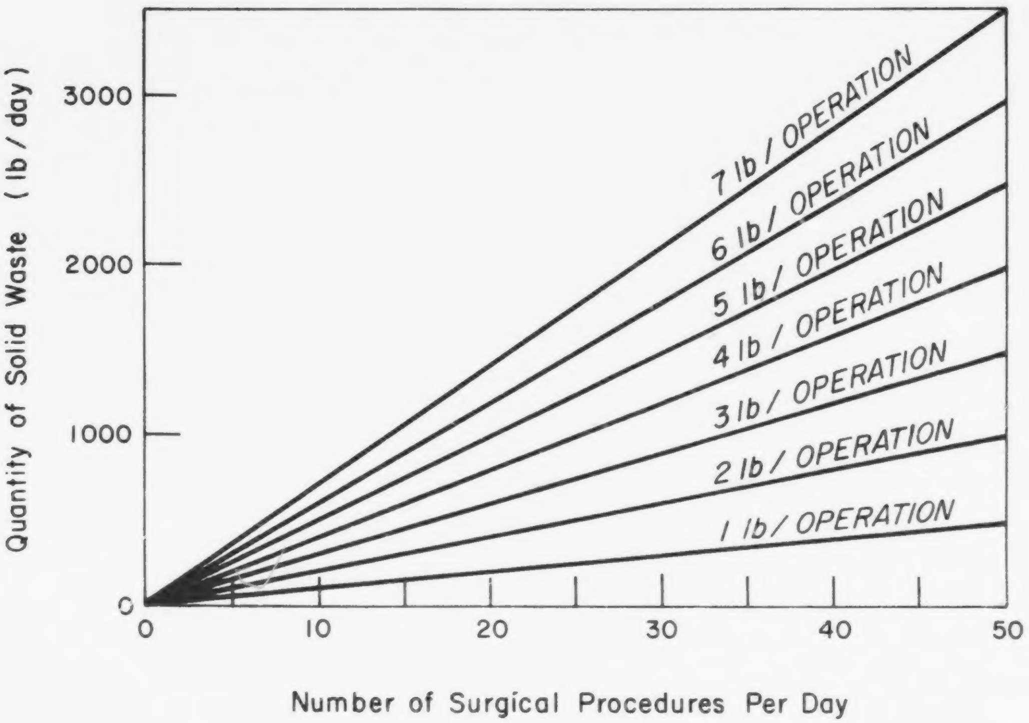

Figure 3.5 Showing additional quantity of solid waste generated per day by the use of disposable surgical items as a function of the number of operations performed per day and the actual quantity of disposable surgical items used per operation.

surgical items used per operation for a particular hospital.

Table 3.4 shows the estimated quantity of solid waste generated in a 500 bed hospital in SMSA which uses computer services; certain dietary, linen and surgical disposables; and performs an average of 25 surgical procedures per day.

3.2.8 Estimation of Waste Quantities for the Various Categories Adopted in this Study

The estimates for the amount of waste in various categories adopted in this study are:

infectious waste - 4 percent*

burnable non-infectious waste - 83 percent [18]

pulpable non-infectious waste - 88 percent (estimated by pulper manufacturers)

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*The estimate for the amount of waste in the infectious category depends on the definition of the "infectious waste". The estimate for the amount of infectious waste in this study has been adopted from the estimate of the Hospital Council of Southern California [36].

TABLE 3.4

TOTAL ESTIMATED QUANTITY OF SOLID WASTE GENERATED PER DAY FOR A REPRESENTATIVE 500 BED HOSPITAL

Item	Solid Waste Contribution	Total Solid Waste Generated (lb/Day)
500 bed hospital in SMSA exclusive of disposables and computer service	8.5 lb/patient	4250 (From Figure 3.3)
Computer service	0.050 lb/patient	
Disposable cutlery	0.141 lb/patient	
Disposable dishes	0.657 lb/patient	
Disposable wash cloths	0.022 lb/patient	
Disposable face towels	0.065 lb/patient	
	0.935 lb/patient	500 (From Figure 3.4)
Disposable masks	0.105 lb/operation	
Disposable caps	0.112 lb/operation	
Disposable gloves	1.344 lb/operation	
Disposable gowns	2.191 lb/operation	
	3.752 lb/operation	94* (From Figure 3.5)
Total quantity of solid waste generated per day including disposablesand computer service		4844

*Assuming 25 operations per day.

CHAPTER IV

COST FUNCTIONS

4.1 Introduction

Chapter I classified the activities involved in a complete hospital solid waste handling system into the following four stages:

(i) Collection of waste within the hosital

(ii) Treatment of waste at the hospital site

(iii) Transportation of waste from the hospital

(iv) Final processing and ultimate disposal

The available alternative systems for handling hospital solid waste at each of these stages were laid out in the form of a decision tree in Figure 1.4.

This chapter develops cost functions for the various alternate systems available at each of the above stages. These cost functions relate the cost of different systems to pertinent hospital parameters and relevant hospital management policies relating to waste handling. This chapter uses a functional approach to costs as this approach has a wider scope in the extrapolation of cost estimates for different situations. The two components of the total cost of the system are:

(i) Capital cost, which represents the initial cost required to install the system and make it operational; and

(ii) Operating cost, which represents the expense involved to keep the system running.

The cost functions are developed in two stages. The first stage relates the capital cost to the hardware parameters, which in turn are related to the appropriate hospital parameters. The second stage relates the operating cost to hardware parameters and relevant hospital management policies relating to waste handling.

The limited reliable data available on capital cost shows large variability. The capital cost for the different systems has been synthesized from cost information on the various components of the systems. The lack of data on the operating cost necessitated developing the cost functions for the operating cost by delving deeper into the genesis of the operating cost. The total operating cost of a system has been divided into several identifiable components such as the costs of material, labor, and utilities, each of which has been synthesized from several elemental costs making that component. Labor cost has been estimated by breaking down various activities into elemental operations and using standard time estimates for these operations.

The cost information used in estimating the cost functions was obtained through questionnaires to the hospitals, the manufacturers of various equipment and by on-site observations in several hospitals. Copies of and responses to the questionnaire are found in Appendix E and information supplied by manufacturers is tabulated in Appendix E.

In certain cases several hospital activities shared a single facility. For example, hospital elevators are used to transport people, supplies and, in some cases, solid waste. The cost of a shared facility to each activity was proportional to the facility's use by each activity.

4.2 Collection of Waste Within the Hospital

As discussed earlier, in-hospital waste collection involves collection from the points of generation, then its transportation to one or more central storage locations. These operations may be further divided into two sub-stages:

1. Collection of waste from the points of generation and its transportation to the intermediate accumulation points. Initially most waste is deposited in small receptacles, "initial storage points", placed at points of origin of the waste. At suitable intervals the waste from the receptacles is transferred to larger containers, "intermediate accumulation points", placed at suitable locations such as the utility rooms, trash rooms, janitors' closets or maid carts. In some areas such as the kitchen the initial storage points also serve as the intermediate accumulation points.

2. Collection of waste from the intermediate accumulation points and its transportation to one or more central storage locations. The waste from intermediate accumulation points is transported to central storage locations. Alternative systems for transporting waste to central storage locations considered here are:

(i) Manual system;
(ii) Gravity chute-manual system;
(iii) Gravity chute-pneumatic tube system;
(iv) Pneumatic tube system; and
(v) Other automated systems.

The cost of waste collection in sub-stage (i) is similar for all of the alternate systems and can be commonly generated for all the systems. Cost functions for sub-stage (ii) will be generated separately for alternate systems.

4.2.1. Manual System

In the manual system, the workmen manually transfer waste from the intermediate accumulation points to the central storage location using a conventional push cart. The workmen visit the various accumulation points in turn, transfer waste into the carts, and take it to the designated central storage location.

1. Capital Cost. The capital cost of the system includes the cost of the carts for transporting waste, containers used for storage at the intermediate accumulation points, and the building space cost for housing the carts and the containers. The cost of equipment at the central storage location, if any, is not included within the cost of this stage.

Let:

N_1 = number of containers in the system

N_2 = number of carts in the system

C_1 = cost per container

C_2 = cost per cart

a_1 = area of building space, in square feet, allocated for housing the carts and the containers

C_3 = annual rental cost per square foot of building space

Then the capital cost of providing carts and containers for the system is given by $N_1C_1 + N_2C_2$, and the annual rental cost of space is given by a_1C_3.

The annual equivalent capital cost of the system, denoted by Em_1, may be expressed as:

$$Em_1 = (N_1C_1 + N_2C_2)\left(\frac{a}{p}\right)_y^I + a_1C_3 \qquad (1)$$

where I = interest rate per year on the capital;

y = useful life of carts and containers in years; and

$(\frac{a}{p})_y^I$ = capital recovery factor*

In addition to the above equipment, a manual system would involve the use of washing facilities for washing the carts and the containers, and use of elevators for the waste transportation. The use of such facilities is shared with several other hospital activities and appropriate costs for their use is charged against waste handling and is included in the operational and maintenance costs.

2. Operating Cost. The operating cost of the manual system includes labor cost for waste collection, cost of liners, and costs for the use of elevators and washing facilities.

a. Labor cost for waste collection. The product of the average number of man-hours spent per day in waste collection and the average wage rate per hour will give the labor cost per day.

The total collection time has been divided into the following four components:

T_H = horizontal travel time in minutes per day

T_V = vertical travel time in minutes per day

T_L = loading time of carts in minutes per day

T_U = unloading time of carts in minutes per day

Each component has been estimated separately by using normal time+ of elemental operations involved in the component. A 17% allowance, as suggested by Hospital Staffing Methodology Manual[17] for personal needs (coffee breaks, bathroom trips, etc.), job interruptions by supervisors, fatigue, and other minor unavoidable delays has been made to convert normal time into standard time.

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*The capital recovery factor with an interest rate of i per period and with n number of periods is denoted by $(\frac{a}{p})_n^i$, and is given by $\frac{i(1+i)^n}{(1+i)^n-1}$

+Normal time = average time for actually doing the work.

If T_N and T denote the normal time in minutes and the standard time in hours, respectively, then

$$T_N = T_H + T_V + T_L + T_U \qquad (2)$$

and

$$T = 1.17 \left(\frac{T_N}{60}\right) \qquad (3)$$

The annual labor cost denoted by Em_3, can be expressed as

$$Em_3 = 365(TC) \qquad (4)$$

where C = average wage rate per hour including overhead.

Estimation of the above four components of the total collection time is based on two assumptions:

(i) The frequency of waste collection from all the intermediate accumulation points on a floor is the same; and

(ii) Collection on each floor starts with a new trip.

The following notations are used in identifying elements essential to the estimation of the component times and the total collection time:

N = number of floors in the hospital building

A_i = area of the ith floor in square feet

P_i = perimenter of the ith floor in feet

n_i = number of intermediate accumulation points on the ith floor from which waste is to be collected

F_i = frequency of collection per day for the ith floor

d = distance from the elevator to the central storage location in feet. If there is more than one elevator, then d will be average distance.

t_e = normal time in man-minutes required for emptying one lined waste receptacle. This includes the time required for the removal of the liner from the receptacle, placing the waste in the cart, and placing a new liner in the receptacle

t_s = normal walking speed while pushing a cart on the hospital floors

t_r = normal time in man-minutes for removing one bag from the cart and placing it in a container at the central storage location

t_v = normal time in man-minutes for elevator travel per floor

t_w = normal time in man-minutes spent waiting for an elevator

t_o = normal time in man-minutes for loading and unloading a cart in an elevator

W_i = average amount of waste in pounds to be collected from the ith floor per day

W_c = average effective capacity of the cart in pounds

a.1. Horizontal Travel Time (T_H). The physical characteristics of the hospital building greatly influence the horizontal travel time. To estimate the horizontal distance traveled, the building shapes are classified into the following two categories:

I. Building shapes such as Y, T, H, X, etc., where the length of the building is significantly greater than the width. The distance traveled in taking a full round of a floor for these shapes would be approximately equal to its perimeter, as the worker collecting waste will travel along the corridors.

II. Building shapes such as square, circular, octagonal, etc., where neither side is dominating, so waste collection requires visiting waste accumulation points scattered more or less uniformly over the whole floor area. The shortest distance traveled in this case in visiting all points may be approximated by $\sqrt{A_i n_i}$ where A_i denotes the area of the floor and n_i the number of waste accumulation points.[3]

The average amount of waste to be collected per round from the ith floor equals $\frac{W_i}{F_i}$. If L_i denotes the number of trips required per round for the ith floor, then $L_i = \left[\frac{W_i}{F_i W_c}\right]$, where $\left[\frac{W_i}{F_i W_c}\right]$ denotes the next **integer** value of $\frac{W_i}{F_i W_c}$. The total ith floor area (A_i) is divided into L_i sections, and the waste from each section is collected in a separate trip. Let H_i denote the horizontal distance traveled per round for the ith floor. Assuming that waste travels through one elevator, H_i for the building categories I and II are given by equations 5 and 6 respectively.

$$H_i = P_i + \sum_{j=1}^{L_i} d_{ij} + 2dL_i \tag{5}$$

$$H_i = \sum_{j=1}^{L_i} \left(\sqrt{A_{ij} n_{ij}} + d_{ij}\right) + 2dL_i \tag{6}$$

where A_{ij} = area of the jth section on the ith floor in square feet;

n_{ij} = number of intermediate accumulation points in the jth section on the ith floor; and

d_{ij} = distance of jth section from the elevator on the ith floor in feet.

For the floor having the central collection place, the distance d_{ij} denotes the distance of the jth section from the central collection place. For the section containing the elevator or for two sections adjacent to the elevator, the distance d_{ij} equals zero because the trip can be started from and ended at the elevator.

If $L_i = 1$, then $A_{ij} = A_i$; $n_{ij} = n_i$; $d_{ij} = 0$ and equations 4 and 5 reduce to

$$H_i = P_i + 2d, \text{ for building category I}$$
$$H_i = \sqrt{A_i n_i} + 2d, \text{ for building category II} \qquad (7)$$

The distance, d, for the floor having the central collection place will be zero, because the trip can be started from and ended at the central collection place.

The total horizontal distance for all floors would be the sum of the distances for the individual floors. The total horizontal travel time in minutes per day for the whole building can be expressed as

$$T_H = \sum_{i=1}^{N} (H_i F_i) t_s \qquad (8)$$

a.2. Loading time (T_L). The loading time in minutes per day is given by multiplying the total number of waste liners collected per day by the normal time for handling one waste liner, and can be expressed as

$$T_L = \sum_{i=1}^{N} (n_i F_i) t_e \qquad (9)$$

a.3. Vertical travel time (T_V). Because no vertical travel time is involved in transporting waste from the floor having the central storage location, the vertical travel time in minutes per day is given by multiplying the total number of trips per day to the other floors by the normal time for one trip. The average number of floors traveled per trip can be taken as $\frac{N-1}{2}$, since the floor having the central storage location involves no vertical travel time. The total vertical travel time in minutes per day can be expressed as

$$T_V = 2\left[\left(\frac{N-1}{2}\right)t_v + t_w + t_o\right]\sum_{i=1}^{N-1} F_i L_i \qquad (10)$$

a.4. Unloading time (T_U). The unloading time in minutes per day, given by multiplying the total number of waste liners unloaded per day by the normal time for unloading one liner, can be expressed as

$$T_U = \sum_{i=1}^{N} (n_i F_i) t_r \qquad (11)$$

b. Cost of the liners. The number of liners used per day for waste collection equals $\sum_{i=1}^{N} F_i n_i$. The annual cost of liners, denoted by Em_4, can be expressed as

$$Em_4 = 365\left(\sum_{i=1}^{N} F_i n_i\right) C_4 \qquad (12)$$

where C_4 = cost of one liner.

c. Costs for the use of elevators and washing facilities.

c.1. Use of elevator. Since the elevator is shared with many other hospital activities, expenditure for the waste handling function must be appropriately allocated. The cost per hour for elevator use is estimated, then multiplied by the vertical travel time in hours for waste handling to obtain total elevator cost to be assigned to waste handling. The annual depreciation cost and the annual maintenance cost, converted to cost per hour on the basis of number of hours the elevator is used every day, are added to electricity cost for running the elevator. The total cost per hour for the use of an elevator can be expressed as

$$e = \frac{E_1 + E_2}{365H} + W_e C_5 \qquad (13)$$

where e = total cost per hour for using an elevator;

E_1 = annual amortized elevator capital cost;

E_2 = annual maintenance cost;

H = average number of hours the elevator is used per day;

W_e = power consumed by the elevator per hour in kilowatts; and

C_5 = electricity cost per kilowatt hour.

The annual cost of the use of elevators for waste handling, denoted by Em_5, can be expressed as

$$Em_5 = 365 \left(\frac{T_V}{60}\right) e \qquad (14)$$

c.2. Use of washing facilities. Because limited use is made of washing facilities for waste handling, the small cost involved is neglected.

Total annual operating cost, denoted by Em_2, is given by

$$Em_2 = \text{annual labor cost} + \text{annual cost of liners} + \text{annual cost of elevator for waste handling} = Em_3 + Em_4 + Em_5 \qquad (15)$$

3. Values of the parameters.

a. Normal time. The Hospital Staffing Methodology Manual[17] suggested the following values of normal time for the activities involved in the manual system. The Hospital Systems Research Group of the University of Michigan conducted an extensive time and motion study in a number of hospitals to develop the estimates in the Manual.

t_e* = 1.0 man-minutes per receptacle = normal time for emptying one lined waste receptacle

t_s* = 0.006 man-minutes per foot = normal walking speed while pushing a cart on the hospital floors

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*The actual values suggested in the manual for t_e and t_s are 0.99 man-minutes and 0.006 man-minutes per foot + 0.012 man-minutes for each start and stop combination, respectively. The values used in the present study have been modified by taking out the latter part of t_s and adding it to the value of t_e.

t_r = 0.12 man-minutes per item = normal time for unloading one bag at central storage location

t_v = 0.09 man-minutes per floor = normal time for elevator travel per floor

t_w = 1.37 man-minutes = normal time spent waiting for an elevator

t_o = 0.62 man-minutes = normal time for unloading and loading cart into an elevator

b. Size and number of containers and carts. The recommended size of containers to be used as intermediate accumulation points is 4.0 cu.ft. which will handle 15 pounds of waste* at 80% effective utilization of its capacity. The number of containers (n_i) on the ith floor would be given by $\frac{W_i}{15F_i}$, where W_i is the average amount of waste in pounds per day to be collected from the ith floor and F_i is the frequency of collection per day on the ith floor. The total number of containers on all floors equals $\sum n_i$.

Suggested size of the cart is one cubic yard which can handle 100 pounds of waste at 80% effective utilization. The number of carts required would depend upon the number of working hours for waste collection, floor dimensions, cart size, and the number of simultaneous collections. The minimum suggested number is at least one cart for every building, plus one additional cart as a standby.

The suggested sizes of the containers and the carts have been derived from the opinions of several knowledgeable people in the fields of public health and hospital management based on personnel safety, ease of handling, physical dimensions of doors and elevators and other considerations.

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*This assumes density of waste at 125 pounds per cubic yard.

c. Building space. Several people in the field of hospital management suggested that 4 sq. ft. of building space be allocated for each container and 25 sq. ft. for each cart.

d. Cost parameters and current estimates. The estimates for the cost parameters have been derived from several sources. The labor wage rate (C) represents the average present (1972) labor rate for the corresponding category of work in the state of Minnesota. Similarly, the electricity rate (C_5) represents the current rate which the hospitals in the Twin City area pay for the electricity units consumed beyond certain minimum units. The estimates for the prices of carts (C_1), containers (C_2), and liners (C_4) have been made from the prices quoted by several manufacturers and the prices actually paid by several hospitals for these items. The elevator cost (E_1, E_2) represents the typical elevator cost in the Twin City area obtained from the University of Minnesota. The rental cost of space (C_3) was obtained from hospital consultants and real estate people. The estimates for these cost parameters are as follows:

C = \$3 per hour = average wage rate including overhead

C_1 = \$250 per cart = cost per cart

C_2 = \$20 per container = cost per container

C_3 = \$2 per square foot per year = annual rental cost of building space

C_4 = \$0.06 per liner = cost per liner

C_5 = \$0.02 per kilowatt hour = electricity cost

E_1 = \$8,500 per year = annual amortized capital cost of an average size elevator for a five story building. For taller buildings add $1,400 per additional floor.

E_2 = $4,000 per year = annual elevator maintenance cost

e. Miscellaneous parameters.

y = 10 years (given by manufacturers) = useful life of carts and containers

I = 10% interest rate per year on the capital

H = 18 hours (given by hospitals) = average hours per day of elevator use

4.2.2 Gravity Chute - Manual System

As soon as a container or a liner at the intermediate accumulation point is full, it can be removed immediately and deposited into the gravity chute for vertical movement. Consequently, the waste does not wait for collection as in the manual system. Typically, the waste accumulates at the bottom of the gravity chute in a cart which is then transported to the central storage location.

1. Capital cost. The equipment used in this system consists of carts, containers, plus the gravity chutes and appurtenances. The capital cost also should include the cost of the building space required both on the various floors to house the containers and chutes and at the bottom of the chutes to house the waste discharge arrangements and the carts. The capital cost of a gravity chute will depend upon the size, thickness, and length of the chute; number and type of openings for feeding waste; type of arrangement for discharging waste; and other auxiliary equipment such as baffles, electric interlocks, and sanitizing units. The cost of building work required for installation of the

chutes would be another component of capital cost.

The most important parameter for a typical gravity chute is the number of openings, which corresponds to the number of floors. Usually cost data are available on the basis of an intake section defined, for the purpose of this study, as the portion of a gravity chute between two openings.

Let:

M = number of gravity chutes
i = index of a gravity chute
m_i = number of intake sections in the ith gravity chute
C_6 = cost of intake section, including building preparation work and installation
C_7 = cost of one discharge door arrangement including installation
N_1 = number of containers in system
N_2 = number of carts in system
C_1 = cost per container
C_2 = cost per cart
a_1 = area of building space, in square feet, allocated for housing the carts and the containers
C_3 = annual rental cost per squre foot of building space

Then the equipment cost of the gravity chutes denoted by Cg, can be expressed as

$$Cg = \sum_{i=1}^{M} m_i C_6 + MC_7 \qquad (1)$$

The capital cost of the containers and carts is given by $N_1C_1 + N_2C_2$, and the annual cost for building space rental is given by a_1C_3 as in the manual system.

The annual equivalent cost of the gravity chute-manual system, denoted by Eg_1, can be expressed as

$$Eg_1 = (N_1C_1 + N_2C_2)\ (\frac{a}{p})^I_y + Cg\ (\frac{a}{p})^I_z + a_1C_3 \qquad (2)$$

where I = interest rate per year;

y = useful life of carts and containers in years;

z = useful life of gravity chutes in years; and

$(\frac{a}{p})^I_y$, $(\frac{a}{p})^I_z$ = capital recovery factors (see footnote p.57).

2. Operating cost. The operating cost of a gravity chute-manual system includes the labor cost, the cost of the liners, and other miscellaneous costs for maintenance, sanitation and repairs.

a. Labor cost. Since gravity chutes are used for moving the waste vertically, the collection time in this case does not involve any vertical time but additional labor is required to clean the chutes. Again the total labor time can be divided into four components:

T_H = horizontal travel time in minutes per day

T_L = loading time of chutes in minutes per day

T_U = unloading time of carts in minutes per day

T_C = cleaning time for chutes in minutes per day

Each component has been estimated separately as in the manual case. The total normal time, in minutes per day, is given by

$$T_N = T_H + T_V + T_L + T_C \qquad (3)$$

and the total standard time, in hours per day, is given by

$$T = 1.17(\frac{T_N}{60}) \qquad (4)$$

The annual labor cost denoted by Eg_3, can be expressed as

$$Eg_3 = 365(TC) \qquad (5)$$

where C = average wage rate per hour including overhead.

The following notation is used:

A = total area of all floors in square feet

n = number of intake sections, given by $\sum_{i=1}^{M} m_i$

W = total amount of waste in pounds

w = average amount of waste in pounds carried per trip from intermediate accumulation points to the gravity chutes

W_c = average amount of waste in pounds transported per trip from bottom of the chutes to the central storage location

t_p = normal walking speed in man-minutes per foot while carrying a load

t_s = normal walking speed in man-minutes per foot while pushing a cart

d_a = average distance from bottom of chutes to the central storage location in feet

t = normal time in man-minutes required for picking one bag from the intermediate accumulation point and putting it into the chute (does not include travel time)

t_r = normal time in man-minutes for removing a bag from cart and placing it in a container at the central storage location

a.1. Horizontal travel time (T_H). The average horizontal distance between intake sections on a floor equals $\sqrt{\frac{A}{n}}$.

The average distance per trip (both ways) from the intermediate accumulation point to the gravity chute intake is $0.76\sqrt{\frac{A}{n}}$.

Total number of trips required for feeding waste into the chutes is $\frac{W}{w}$.

Total horizontal distance covered on floors in charging waste is $0.76\sqrt{\frac{A}{n}}\,(\frac{W}{w})$.

Number of trips needed to transport waste from the bottom of the chutes is $\frac{W}{W_c}$.

Total horizontal distance covered in taking waste from the bottom of the chutes to the central storage is $2d_a\,(\frac{W}{W_c})$.

The horizontal travel time in minutes per day can be expressed as

$$T_H = 0.76\sqrt{\frac{A}{n}}\,(\frac{W}{w})\,t_p + 2d_a\,(\frac{W}{W_c})ts \qquad (6)$$

a.2. Loading time (T_L). The loading time in minutes per day for charging the waste into chutes, obtained by multiplying the total number of bags charged per day by the normal time of handling one bag, is given by

$$T_L = (\frac{W}{w})t \qquad (7)$$

a.3. Unloading time (T_U). The unloading time in minutes per day, for unloading carts obtained by multiplying total number of bags unloaded per day by the normal time of unloading one bag, is given by

$$T_U = (\frac{W}{w})t_r \qquad (8)$$

a.4. Cleaning time (T_C). A very nominal amount of work is required to clean and disinfect chutes, and the areas for charging and discharging. If the recommended half-hour time for cleaning each chute is alloted every day, the cleaning time in minutes per day is given by

$$T_C = 30M \qquad (9)$$

where M is the number of chutes.

b. Cost of the liners. The number of liners used per day equals $\frac{W}{w}$. The annual cost of liners, denoted by Eg_4, can be expressed as

$$Eg_4 = 365(\frac{W}{w})C_4 \tag{10}$$

where C_4 = cost of one liner.

c. Miscellaneous cost. The relatively small miscellaneous costs, including the cost of the disinfectant, water, electricity and other supplies used to operate and maintain the system are ignored.

The total annual operating and maintenance cost, denoted by Eg_2, is given by

$$Eg_2 = \text{annual labor cost} + \text{annual cost of liners} = Eg_3 + Eg_4$$

3. Values of the parameters. Again, as in the manual system, the normal time values given here are taken from the Hospital Staffing Methodology Manual[17]. For estimates of remaining parameters, the discussions given under manual system apply here also.

a. Normal time.

t_p = .005 man-minutes per foot = normal walking speed while carrying a load

t_s = .006 man-minutes per foot = normal walking speed while pushing a cart

t = 1.26 man-minutes per item = normal time for charging one bag into a chute

t_r = 0.12 man-minutes per item = normal time for removing one bag from a cart and depositing it in a container at the central storage location

b. Size and number of containers and carts. The recommended size container is the same as used in the manual system, i.e., 4 cubic feet. At 90% effective utilization, each container would handle 18 pounds of waste. The minimum number of containers suggested is at least one container for every 20 beds.

Again, the recommended cart size is one cubic yard with an effective carrying capacity of 120 pounds. The minimum number of carts is one for every chute, plus one as a standby.

In the manual system, an 80% utilization figure was used to estimate the effective capacities of the containers and carts. This was to insure that in calculating the number of containers and collection trips needed, 1) a sufficient number of containers would be provided to store the waste at the intermediate accumulation points and 2) a sufficient number of collection trips would be made to prevent overloading of carts.

c. Building space. The allocation of building space is suggested at 4 square feet for each container, 50 square feet for every charging station, and 80 square feet for each chute room at the bottom of a chute.

d. Cost parameter and current estimates.

C = \$3 per hour = average wage rate including overhead

C_1 = \$250 per cart = cost per cart

C_2 = \$20 per container = cost per container

C_3 = \$2 per year per square foot = annual rental cost of building space

C_4 = \$0.06 per liner = cost per liner

C_6 = \$1100 per intake section = cost per intake section

C_7 = \$500 per discharge door arrangement = cost per discharge door arrangement at the bottom of a chute

e. Miscellaneous parameters.

y = 10 years (given by manufacturers) = useful life of containers and carts

I = 10% = interest rate per year on the capital

z = 50 years (given by manufacturers) = useful life of gravity chute

4. Optimum number of intake sections. The optimum number of intake sections is the value of n which minimizes the sum of the cost of traveling from the intermediate accumulation points to a gravity chute intake section, the cost of cleaning the chutes, and the cost of the intake sections. Assume the number of intake sections, m_i, to be the same for each gravity chute which equals the number of floors in the hospital building.

Traveling cost per year is given by

$$365 \left[1.17 \left(\frac{W}{w}\right) 0.76 \sqrt{\frac{A}{n}} \left(\frac{t_p}{60}\right) \right] C$$

The annual cost of cleaning is given by

$$365 \left[\frac{1}{2} \left(\frac{n}{m_i}\right) \right] C$$

The annual cost of providing intake sections is given by

$$\left[nC_6 + \left(\frac{n}{m_i}\right) C_7 \right] \left(\frac{a}{p}\right) \frac{I}{z} + C_3 \left[na_{11} + \left(\frac{n}{m_i}\right) a_{12} \right]$$

where a_{11} = area per charging station

a_{12} = area for each chute room at the bottom of the chute.

Total cost of traveling, providing intake sections, and cleaning (denoted by C_c) is given by

$$C_c = 365\left[1.17\ \left(\frac{W}{w}\right)\ 0.76\sqrt{\frac{A}{n}}\ \left(\frac{t_p}{60}\right)\right] C + 365\left[\frac{1}{2}\left(\frac{n}{m_i}\right)\right] C + \left[nC_6 + \left(\frac{n}{m_i}\right)C_7\right]\left(\frac{a}{p}\right)^I_z + C_3\left[na_{11} + \left(\frac{n}{m_i}\right)a_{12}\right] \tag{12}$$

Differentiating equation (12) with respect to n and equating it to zero gives the optimal value of n, denoted by N_{opt}.

$$N_{opt} = \left[\frac{1}{2}\ \frac{365\left[1.17\left(\frac{W}{w}\right)\ 0.76\sqrt{A}\ \left(\frac{t_p}{60}\right)\right] C}{\left(C_6 + \frac{C_7}{m_i}\right)\ \left(\frac{a}{p}\right)^I_z + C_3\left(a_{11} + \frac{a_{12}}{m_i}\right) + 365\left(\frac{1}{2}\right)\left(\frac{C}{m_i}\right)}\right]^{\frac{2}{3}} \tag{13}$$

4.2.3 Gravity Chute-Pneumatic Tube System.

This system differs from the gravity chute - manual system in that the movement of waste from the bottom of the chutes to the central storage location is through a pneumatic tube. The two types of gravity chute-pneumatic tube systems use either a valve or a make-up air source at the bottom of each chute to transfer waste from the gravity chute to the pneumatic tube.

The mode of waste collection and movement on the floor remains the same as in the gravity-chute manual system, but stronger bags are required for waste containment to move waste through this system. Although the two gravity-pneumatic systems are essentially similar, cost formulas are developed for the system using valves because more information is available on that system.

1. *Capital Cost*. In addition to the containers and the gravity chutes, the equipment in this system consists of discharge valves at the bottom of chutes, tubing, collection hoppers, blower, and a control system including wiring, conduits and panels. Capital cost also should

include the cost of the building space required for housing various pieces of equipment. The capital cost of the containers is given by N_1C_1 as in the manual system where N_1 is the number of containers and C_1 is the cost per container. The capital cost of the gravity chutes, pneumatic tube, and other equipment will depend upon the size, thickness, length, number of gravity chutes and pneumatic tubes, number and type of openings for feeding waste, type of installation (buried pipes, raised pipes, tunnel fittings, etc.), number of bends in the pneumatic tubes, type of control system, waste discharge arrangements, and other auxiliary pieces of equipment. For a typical gravity chute-pneumatic tube system (with fixed size, thickness, and story height), the most important parameters are the number of chutes, number of openings, length of the pneumatic tube, and complexity of the control system. The costs of gravity chutes and pneumatic tube equipment, denoted by Cq and Cp respectively, can be expressed as

$$Cq = \sum_{i=1}^{M} m_i C_6 \quad \text{and} \tag{1}$$

$$Cp = MC_7 + LC_8 + C_9 + C_{10} + C_{11} \tag{2}$$

where M = number of gravity chutes;

i = index of gravity chutes;

m_i = number of intake sections in the ith gravity chute;

C_6 = cost per intake section including building preparation work and installation;

C_7 = cost per discharge valve;

L = total length of pneumatic tube;

C_8 = cost per foot of the pneumatic tube including installation, welding, excavation, and allowance for fittings and air inlets;

include the cost of the building space required for housing various pieces of equipment. The capital cost of the containers is given by N_1C_1 as in the manual system where N_1 is the number of containers and C_1 is the cost per container. The capital cost of the gravity chutes, pneumatic tube, and other equipment will depend upon the size, thickness, length, number of gravity chutes and pneumatic tubes, number and type of openings for feeding waste, type of installation (buried pipes, raised pipes, tunnel fittings, etc.), number of bends in the pneumatic tubes, type of control system, waste discharge arrangements, and other auxiliary pieces of equipment. For a typical gravity chute-pneumatic tube system (with fixed size, thickness, and story height), the most important parameters are the number of chutes, number of openings, length of the pneumatic tube, and complexity of the control system. The costs of gravity chutes and pneumatic tube equipment, denoted by Cq and Cp respectively, can be expressed as

$$Cq = \sum_{i=1}^{M} m_i C_6 \quad \text{and} \tag{1}$$

$$Cp = MC_7 + LC_8 + C_9 + C_{10} + C_{11} \tag{2}$$

where M = number of gravity chutes;

i = index of gravity chutes;

m_i = number of intake sections in the ith gravity chute;

C_6 = cost per intake section including building preparation work and installation;

C_7 = cost per discharge valve;

L = total length of pneumatic tube;

C_8 = cost per foot of the pneumatic tube including installation, welding, excavation, and allowance for fittings and air inlets;

C_9 = cost of blower, as a function of L;

C_{10} = cost of control system, as a function of M and L; and

C_{11} = cost of auxiliary equipment such as sound attenuators, collection hoppers, filters, control panels, etc.

Required building space is divided into two types:

(i) building space for housing containers, chutes, and the discharge valves; and

(ii) building space for housing blower and collection equipment, which may be less expensive than the first type.

Let a_1 and a_2 denote the areas of building space in square feet of the first and second types, respectively, and C_{3_1} and C_{3_2} the rental costs per year per square foot of space for the first and second types, respectively. Then the annual rental cost of space is given by $a_1C_{3_1} + a_2C_{3_2}$.

The annual equivalent capital cost of the system, denoted by Et_1, is given by

$$Et_1 = (N_1C_1)(\frac{a}{p})^I_y + (Cq)(\frac{a}{p})^I_z + (a_1C_{3_1} + a_2C_{3_2}) + (Cp)(\frac{a}{p})^I_x \quad (3)$$

where I = interest rate per year on the capital;

y = useful life of carts and containers in years;

z = useful life of gravity chutes in years;

x = useful life of pneumatic tube equipment in years; and

$(\frac{a}{p})^I_y$, $(\frac{a}{p})^I_z$, $(\frac{a}{p})^I_x$ = capital recovery factor (see footnote p. 57).

2. Operating Cost. The operating cost of the gravity chute-pneumatic tube system includes the costs of labor, the liners or bags,

electricity and miscellaneous maintenance.

a. Labor cost. Labor cost again can be divided into two components, labor cost for waste collection and labor cost for cleaning. The total labor time can be divided into the following three components:

T_H = horizontal travel time in minutes per day

T_L = loading time in minutes per day

T_C = cleaning time in minutes per day

The total normal time in minutes per day, T_N, is given by

$$T_N = T_H + T_L + T_C \tag{4}$$

and the total standard time in hours per day, T, is given by

$$T = 1.17(\frac{T_N}{60}). \tag{5}$$

The annual labor cost, denoted by Et_3 can be expressed as

$$Et_3 = 365(TC) \tag{6}$$

where C = average wage rate per hour including overhead.

As in the gravity chute-manual system, the above three components of the total time can be expressed as

$$T_H = 0.76\sqrt{\frac{A}{n}}\,(\frac{W}{w})t_p \tag{7}$$

$$T_L = (\frac{W}{w})t \tag{8}$$

$$T_C = 30M \tag{9}$$

where A = total area of all floors in square feet;

n = total number of gravity chute intake sections;

W = total amount of waste in pounds;

w = average amount of waste in pounds carried per trip from intermediate accumulation points to the gravity chutes;

t_p = normal walking speed in man-minutes per foot while carrying a load;

t = normal time in man-minutes required for taking one bag from the intermediate accumulation point and putting it into the chute (does not include travel time); and

M = number of gravity chutes.

b. Cost of liners. The annual cost of liners, denoted by Et_4, is given by

$$Et_4 = 365(\frac{W}{w})C_4 \qquad (10)$$

where C_4 = cost of one liner.

c. Electricity cost. Let S be the speed in feet per second at which the waste travels through the pneumatic tube. Then the time required for transporting one load equals $\frac{L}{S}$. If it takes α seconds to open and close one valve, then the time per discharge of a load equals $(\frac{L}{S}) + \alpha$ seconds. The number of discharges per day equals $\frac{W}{\beta}$, where β is the average weight discharged each time the valve opens. If a blower rated at K horsepower is used to run the system, then the total electricity consumption in kilowatt hours per day, denoted by P_p, is given by

$$P_p = 0.746K\ (\frac{W}{\beta})(\frac{L}{S} + \alpha)(\frac{1}{3600}) \qquad (11)$$

and the annual electricity cost, denoted by Et_5, is given by

$$Et_5 = 365(P_p C_5) \qquad (12)$$

where C_5 = electricity rate per K.W.H.

d. Miscellaneous costs. The miscellaneous costs consist of mechanical maintenance and repairs required on equipment, plus alternate methods used for waste transportation when the system fails. This per annum cost has been suggested as 5 percent of the capital cost of the equipment.

3. Values of the Parameters.

a. Normal time.

t_p = 0.005 man-minutes per foot = normal walking speed while carrying a load

t = 1.26 man minutes per item = normal time required for taking one bag from the intermediate accumulation point and putting it into the chute

b. Size and number of containers.

Size: 4 cubic feet

Number: at least one container for every 20 beds

c. Building space.

Container: 4 square feet

Valve room: 48 square feet

Charging station: 80 square feet

Exhauster and collection equipment: 2000 square feet

d. Cost parameters and current estimates.

C = \$3 per hour = average wage rate including overhead

C_1 = \$20 per container = cost per container

C_{3_1} = \$20 per square foot = annual rental cost of space to house containers, chutes and discharge valves

C_{3_2} = \$10-20 per square foot = annual rental cost of space to house blower and collection equipment

C_4 = \$0.06 per liner = cost per liner

C_5 = \$0.02 per K.W.H. = electricity cost

C_6 = \$1100 per intake section = cost per gravity chute intake section

C_7 = \$7,200 per discharge valve = cost per discharge valve

C_8 = \$40-50 per foot = cost of pneumatic tube

$$C_9 = \begin{cases} \$9{,}000 \text{ for } L \leq 200 \\ \$9{,}000 + 2(L-200) \text{ for } L > 200 \end{cases} \quad \left\{ \begin{array}{l} \text{cost of blower as a function} \\ \text{of the total length of the} \\ \text{pneumatic tube } (L) \end{array} \right.$$

C_{10} = 9L + 1800M = cost of control system

C_{11} = \$30,000 = cost of auxiliary equipment

e. Miscellaneous parameters.

S = 50 feet per second = speed of travel through pneumatic tube

α = 30 seconds = time to open and close discharge valve

β = 100 pounds = average weight discharged each time the valve opens

I = 10% per year = interest rate on the capital

y = 10 years (given by manufacturers) = useful life of containers and carts

z = 50 years (given by manufacturers) = useful life of gravity chute

x = 25 years (given by manufacturers) = useful life of pneumatic tube equipment

$$K = \begin{cases} 50 \text{ for } L \leq 200 \\ 50 + 4(L-200) \text{ if } L > 200 \end{cases} \quad \left\{ \begin{array}{l} \text{horsepower of the blower as} \\ \text{a function of the total length} \\ \text{of the pneumatic tube } (L) \end{array} \right.$$

4. Optimum Number of Intake Sections. The optimum number of intake sections for this system can be computed in the same way as in the gravity chute-manual system.

$$N_{opt} = \left[\frac{1}{2} \, \frac{365\left[1.17(\frac{W}{w}) \; 0.76\sqrt{A} \; (\frac{t_D}{60})\right] C}{C_6(\frac{a}{p})^{I}_{z} + (\frac{C_7}{m_i})(\frac{a}{p})^{I}_{x} + C_{3_1}(a_{1_1} + \frac{a_{1_2}}{m_i}) + 365(\frac{1}{2})(\frac{C}{m_i})} \right]^{\frac{2}{3}}$$

4.2.4 Pneumatic Tube System.

In the pneumatic tube system, both the vertical chutes and the horizontal tube are maintained under negative pressure. The mode of waste collection and movement remains the same as in the gravity chute-pneumatic tube system.

Although cost data are unavailable on this system, the capital cost will not differ significantly from that of the gravity chute-pneumatic tube system. The equipment used is essentially the same as in the gravity chute-pneumatic tube system except that no discharge valves are needed, but additional venting is needed to maintain negative pressure in the vertical tube. However, the electricity cost will be different because only one load can travel through this system at one time. If V denotes the average height of the vertical chutes, then the average time taken per load to travel through the system equals $(\frac{V+L}{S})$ and the number of loads equals $(\frac{W}{w})$.

4.2.5 Other Automated Systems.

Because other automated systems are very expensive, that expense can be justified only for aggregated material movement functions, solid waste being just one of several functions. No cost functions are developed for these systems.

4.3 Treatment of Waste on Hospital Premises.

Cost functions will be discussed for the following methods of treating waste before it leaves the hospital for ultimate disposal:

(i) incineration;

(ii) compaction;

(iii) pulping;

(iv) pulping and incineration.

4.3.1 Incineration

Waste can be reduced to an inert residue by burning at high temperatures in a specially designed multi-chamber incinerator.

1. Capital cost. The capital cost of an incinerator depends upon its burning capacity, type of waste burned, feeding arrangement, air pollution control devices, and other auxiliary equipment. The most important parameter for an incinerator with automatic waste feeding arrangements and air pollution control devices is its burning capacity. Factors that should be considered in determining the appropriate incinerator burning capacity for a particular hospital are discussed in Appendix H. The capital cost, as a function of the burning capacity, can be expressed in a most general form by the following exponential function:

$$C_1 = aQ^b \qquad (1)$$

where C_1 = capital cost of the incinerator;

Q = burning capacity in pounds per hour and

a and b are the parameters to be estimated from the observed data.

Building space cost for housing an incineration unit will depend upon its size, design and other auxiliary equipment. If a_1 is the area in square feet allocated to the unit and C_3 is the rental cost per year per square foot, then the annual building space rental cost is given by a_1C_3.

The annual equivalent capital cost of the system, denoted by

Eb_1, can be expressed as

$$Eb_1 = (aQ^b)(\frac{a}{p})^I_x + (a_1C_3) \qquad (2)$$

where I = interest rate per year on the capital;

x = useful life of incinerator in years; and

$(\frac{a}{p})^I_x$ = capital recovery factor (see footnote p.57).

2. Operating cost. The operating and maintenance costs are comprised of labor cost for waste feeding, ash removal, and cleaning; utility cost for running the unit; and maintenance and repair costs.

a. Labor cost. Since the rated capacity is based on conditions which rarely would be met in practice, the effective burning capacity differs from the rated capacity.

Let $Q' = \alpha Q$ be the effective burning capacity where α is an efficiency factor between 0 and 1

W = amount of waste to be incinerated per day

Then the number of labor hours required per day for operating the incinerator equals $\frac{W}{\alpha Q}$.

Making a time allowance of 25% for removing ashes and cleaning, the total labor hours per day equals $1.25 \frac{W}{\alpha Q}$. The annual labor cost, denoted by Eb_3, can be expressed as

$$Eb_3 = 365(1.25 \frac{W}{\alpha Q})C \qquad (3)$$

where C = average wage rate per hour including overhead.

b. Utility cost. The utility cost, a function of the unit's size and the number of hours in operation, is estimated to vary linearly with the size. The annual utility cost, denoted by Eb_4, can be expressed as

$$Eb_4 = 365(\frac{W}{\alpha Q})QC_2 = 365 \frac{W}{\alpha} C_2 \qquad (4)$$

where C_2 = utility cost per pound per hour.

c. Maintenance and repair costs. The maintenance and repair costs (including parts and labor) per year are estimated at 5% of the capital cost of the equipment. Let this be denoted by Eb_5.

Then the total annual operating cost, denoted by Eb_2, is given by

$$Eb_2 = Eb_3 + Eb_4 + Eb_5 \tag{5}$$

Additional expenses include the cost for hauling and final disposal of the incinerator residue which is assumed to have a density of 500 pounds per cubic yard.

3. Values of the parameters.

$$\left.\begin{array}{l} a = 62 \\ b = 0.87 \end{array}\right\} = \text{computer regression estimates based on cost data supplied by incinerator manufacturers and hospitals}$$

$\alpha = 0.80$ = incinerator efficiency factor

C = \$3.00 per hour = average wage rate including overhead

C_2 = \$0.002 per pound per hour

a_1 = 250 square feet minimum = building space to house the incinerator. The actual value will depend on the type and size of the incinerator.

C_3 = \$1-2 per year per square foot, depending upon the location of the incinerator = annual rental cost of space to house the incinerator

I = 10% per year = interest rate on the capital

x = 10 years (given by manufacturers) = useful life of the incinerator

4.3.2 Compaction.

Cost functions are given here for compaction centralized on the hospital premises.

1. Capital cost. The equipment consists of a compactor to compress the waste and a container to hold the compacted waste. A significant parameter effecting the cost of a compaction system is the capacity of the compactor container. The cost of a container, as a function of its size, can be expressed by the following equation:

$$C_1 = a + br \qquad (1)$$

where C_1 = cost of compactor container;

r = capacity of the container in cubic yards; and

a and b are the parameters to be estimated.

Because several variables affect the cost of a compactor, establishing relationships between the cost and the various parameters of a compactor will require extensive data. With the limited available data, horsepower of a compactor probably is the most suitable parameter for representing its cost because most of the remaining parameters are partially dictated by the horsepower. If C_2 denotes the cost of a compactor, then the equipment cost is given by $C_1 + C_2$.

The annual building space rental cost is given by $a_{1_1} C_{3_1} + a_{1_2} C_{3_2}$ where a_{1_1} and a_{1_2} respectively, are the areas required for the installation and operation of the compaction system and C_{3_1} and C_{3_2}, respectively, are the annual rental costs per square foot for these areas.

The annual equivalent capital cost of the compaction system, denoted by Ec_1, is given by

$$Ec_1 = (C_1 + C_2)(\frac{a}{p})^I_y + (a_{1_1} C_{3_1} + a_{1_2} C_{3_2}) \tag{2}$$

where I = interest rate per year on the capital;

y = useful life of compaction equipment in years; and

$(\frac{a}{p})^I_y$ = capital recovery factor (see footnote p. 57).

2. Operating cost. The operating cost will consist of hauling charges; labor cost for cleaning, maintenance, and operation; and nominal cost for electricity and germicide. The hauling charges have been included here because of the specialized nature of transportation required for the compacted waste. Waste hauling also includes charges for landfill disposal.

a. Hauling cost. The density of compacted waste has been estimated[33] at 320 pounds per cubic yard, so the carrying capacity per hauling trip of a container of r cubic yard is 320r pounds. Yearly trips are given by $\frac{365W}{320r}$ where W is the average amount of waste to be hauled from the hospital every day. The annual hauling cost, denoted by Ec_3, can be expressed as

$$Ec_3 = \frac{365W}{320r} C_4 \tag{3}$$

where C_4 = hauling cost per trip.

b. Labor cost. Labor time for greasing, washing, cleaning, and preparing germicide solution, and other maintenance activities is suggested to be one hour every day per container. Labor time for waste feeding to the compactor approximately equals $(\frac{W}{W_c})t_m$ seconds, where W_c is the average effective capacity of a cart in pounds and t_m is the cycle time of the compactor in seconds.

The annual labor cost, denoted by Ec_4, is given by

$$Ec_4 = 365(1 + \frac{W}{W_c})(\frac{t_m}{3600})C \qquad (4)$$

where C = average wage rate per hour including overhead.

c. Electricity cost. If K is the rated horsepower of the compactor motor, the annual electricity cost (denoted by Ec_5), is given by

$$Ec_5 = 365\ (0.746K)\ \frac{W}{Wc}\ (\frac{tm}{3600}) \qquad (5)$$

where C_5 = electricity rate per kilowatt hour.

d. Germicidal cost. From data obtained from hospitals the cost of germicidal solution may be taken as one dollar per hauling trip. The annual germicidal cost, denoted by Ec_6, is given by

$$Ec_6 = \frac{365W}{320r}\ . \qquad (6)$$

Total annual operating cost, denoted by Ec_2, is given by

$$Ec_2 = Ec_3 + Ec_4 + Ec_5 + Ec_6. \qquad (7)$$

3. Values of the parameters.

a. Size of the container and compactor. The size of a container, limited by weight constraints, rarely exceeds 42 cubic yards, yet a container with a capacity of less than 10 cubic yards is uneconomical for this type of operation. Thus, the best choice ranges between 10 and 42 cubic yards in volume, depending on the hauling charges, amount of waste generated by the hospital, and frequency of hauling waste. Common container sizes are 10, 20, 30 and 40 cubic yards, and the choice will depend on which size offers the lowest total cost for the subject conditions.

According to manufacturers a 5 to 7 1/2 horsepower motor compactor is suggested for a 10 cubic yard container, a 10 horsepower for a

20 cubic yard container, and a 15 horsepower for larger containers.

b. Space requirements. (Suggested by manufacturers).

25' x 10' for a 10 cubic yard container

35' x 10' for a 20 cubic yard container

40' x 10' for larger containers

In addition, a 40' x 10' space is required for the roll-on vehicle to move the container for hauling.

c. Cost and other parameters.

$$\left.\begin{aligned} a &= 340 \\ b &= 875 \end{aligned}\right\} \text{regression estimates based on data supplied by compactor manufacturers and hospitals.}$$

C = \$3.00 per hour = average wage rate including overhead

$$\left.\begin{aligned} C_2 &= \$6{,}000 \text{ for a 15 horsepower compactor} \\ &\quad \$5{,}000 \text{ for a 10 horsepower compactor} \\ &\quad \$4{,}300 \text{ for a 5-10 horsepower compactor} \end{aligned}\right\} \text{average values from data supplied by manufacturers}$$

C_{3_1} = \$2 per year per square foot = rental cost of space for installing compaction system

C_{3_2} = \$1-2 per year per square foot = rental cost of space for operating compaction system

C_4 = 16 + 0.9r for Twin City area = hauling cost per trip (derived from data supplied by Twin City area hospitals)

C_5 = \$0.02 per K.W.H. = electricity rate

I = 10% per year = interest rate on the capital

t_m = 45 seconds = cycle time of a compactor

y = 10 years = useful life of compaction equipment (given by manufacturers)

4.3.3 Pulping

Pulping systems are relatively new for the disposal of hospital solid waste. Although few hospitals now have operative pulping systems, a number of installations are reported under construction around the country. Because hospitals have little working experience with this system, only limited data are available. Similarly, limited cost data are available from manufacturers so only typical cost estimates are given for this system.

1. Capital cost. The basic equipment consists of a pulper and an extractor, along with connecting pipes. A belt conveyor can feed the pulper directly from a gravity chute. The cost changes very slowly with size for a pulper of acceptable quality and features.

Let C_1 denote the cost of a suitable size pulper. The cost of the extractor again changes very slowly with size, and one extractor can be modified to serve more than one pulper. Let C_2 denote the cost of the extractor. The cost of the piping depends mainly on its length, influenced only a little by the diameter of the pipe. If L is the length of the pipe for the typical size diameter and C_3' is the cost per foot, then the piping cost equals LC_3'. Let C_1' be the cost of the container and C_2' be the cost of the automatic feed arrangement. Then the annual equivalent capital cost for the pulping system, denoted by Ep_1, is given by

$$Ep_1 = (C_1 + C_2 + C_1' + C_2' + LC_3')\left(\frac{a}{p}\right)_y^I + (a_1 C_{3_1} + a_2 C_{3_2}) \qquad (1)$$

where I = interest rate per year on the capital;

y = useful life of the pulping equipment in years;

$\left(\frac{a}{p}\right)_y^I$ = capital recovery factor (see footnote p.57);

a_1 = area of building space in square feet required for the installation of a pulping system;

a_2 = area of building space in square feet required for the operation of a pulping system;

C_{3_1} = annual rental cost of building space for housing a pulping system; and

C_{3_2} = annual rental cost of building space for operating a pulping system.

The cost should be appropriately modified for more than one pulper or extractor.

2. Operating cost. The operating cost includes the costs for labor, (cleaning, operation, lubrication, replacement of parts, and repairs), utilities, replacement of parts, and hauling.

a. Labor cost. The annual labor cost, denoted by Ep_3, can be expressed as

$$Ep_3 = T_1C' + T_2C \qquad (2)$$

where T_1 = man-hours spent per year on the pulping system by the engineering staff;

T_2 = man-hours spent per year on the pulping system by the non-engineering staff;

C' = average wage rate per hour for the engineering staff; and

C = average wage rate per hour for the non-engineering staff.

b. Utility costs.

b.1. Electricity. Let H_k denote the combined rated horsepower of all the motors, and h denote the number of hours the pulping system is in actual use per day. The electricity cost per year, denoted by Ep_4, can be expressed as

$$Ep_4 = 365(0.746H_k h)C_5 \quad (3)$$

where C_5 = electricity rate per kilowatt hour.

b.2. Sanitizer. Usually some inexpensive sanitizer is added to the slurry to prevent foaming and to sanitize and deodorize the pulp. Let Ep_5 denote the annual cost of the sanitizer.

b.3. Water. The cost of water depends on the amount and type of waste processed. Let g denote the amount of water consumed in gallons per day, and C_g denote cost per gallon. Then the annual cost of water per year, denoted by Ep_6, is given by

$$Ep_6 = 365(gC_g) \quad (4)$$

b.4. Cost of parts replaced. A number of parts need periodic replacement. Let Ep_7 denote the cost of parts replaced on an annual basis.

Total operating and maintenance cost per year, denoted by Ep_2, is given by

$$Ep_2 = Ep_3 + Ep_4 + Ep_5 + Ep_6 + Ep_7 \quad (5)$$

3. Hauling cost. According to estimates, 300 pounds of waste yield one cubic yard of pulp weighing about 400 pounds. The hauling cost depends on the amount of waste processed, size of the container, and haulage rate per container. If W is the amount of waste to be pulped per day and r cubic yards is the capacity of the container, then the number of trips per year is given by $\frac{365W}{300r}$. The annual hauling cost, denoted by Ep_8, is given by

$$Ep_8 = \left(\frac{365W}{300r}\right)C_4 \quad (6)$$

where C_4 = haulage rate for a container of r cubic yard capacity.

4. Values of the parameters.

C = \$3 per hour = average wage rate for non-engineering staff

C_1 = \$19,000 for 700 pounds/hour
\$21,000 for 1500 pounds/hour
average cost of a pulper, from data supplied by manufacturers and hospitals

C_2 = \$6,000 for 1000 pounds/hour
\$9,000 for 2000 pounds/hour
average cost of an extractor, from data supplied by manufacturers and hospitals

C_{3_1} = \$2 per year per square foot = rental cost of building space for housing a pulping system

C_{3_2} = \$1-2 per year per square foot = rental cost of building space for operating a pulping system

C_5 = \$.02 per K.W.H. = electricity rate

C_g = \$.06 per thousand gallons = water cost

C' = \$6 per hour = average wage rate for engineering staff

C_3' = \$7 per foot = cost of pipe

Ep_5 = \$200 for one pulper = annual cost of water

Ep_7 = \$2000 for a pulper and an extractor = annual cost of replacement parts

$g = \frac{W}{100}$ = amount of water consumed in gallons per day

H_k = 75 horsepower = combined horsepower of all motors

h = depends on the amount of waste processed, type of feed arrangement, etc., but may be assumed to be about 5 hours a day.

T_1 = 343 hours per year = man-hours spent on the pulping system by the engineering staff

T_2 = 548 hours per year = man-hours spent on the pulping system by the non-engineering staff

y = 10 years = useful life of the pulping equipment in years

The parameters, a_1 and a_2, are to be estimated from the number of pulping units and the sizes of pulping units, extractor, container, and truck for moving containers. Manufacturers have suggested the following figures for space allocation:

150 square feet for each pulper

100 square feet for each extractor

250 square feet for each container

400 square feet for each truck.

4.3.4 Pulping and Incineration

The suitability of incinerating the pulp still is under investigation, and only one system is known to have been installed so far. The capital cost of this entire system, which serves a 680 bed hospital, was estimated at $175,000.[20]

4.4 Transportation of Waste from Hospitals

The alternatives available for hauling waste from hospitals are:

(i) municipal service;

(ii) private contract; and

(iii) hauling by hospital in its own trucks.

Some hospitals haul solid waste in their own trucks, however, the costs (capital, operation, maintenance and labor) associated with such a system are prohibitive for most institutions. Private contractors usually haul pulped waste and compacted waste from hospitals because 1) many hospitals lease the compacter and container from the contractor and 2) municipal services do not have, and a hospital cannot afford to purchase, the specialized vehicles needed to haul the large, heavy duty containers.

Actual hauling costs (abstracted from Table 6.1 and Appendices C and F) of compacted, incinerated, untreated and pulped waste are given in Tables 4.1 - 4.4, respectively. The fact that a specialized truck is usually needed to haul the container and that compacted or pulped waste weighs several times more per cu. yd. than incinerated or untreated waste is reflected in the somewhat higher cost per cu. yd. for hauling compacted waste and pulped waste.

TABLE 4.1

COSTS OF HAULING COMPACTED WASTE FROM HOSPITALS

Hauling Cost Per Month	Frequency of Collection Per Month	Volume Per Collection (Cu. Yd.)	Cost Per Cu. Yd.
217	4	42	1.29
230	4	40	1.44
90	2	40	1.12
315	4	44	1.79
458	8	40	1.43
217	4	40	1.36
195	4	40	1.22
560	30	6	3.11
390	8	40	1.22
528	6	40	2.20
80*	24	No data	No data
1,200	16	32	2.34
150	5	20	1.50
950	12	27	2.93
450	30	8	1.88
452+	16	10	2.83
285+	6	40	1.19

* Hospital hauls waste in its own trucks.
+ Hospital incinerates most combustibles.

TABLE 4.2

COSTS OF HAULING INCINERATED WASTE FROM HOSPITALS

Hauling Cost Per Month	Frequency of Collection Per Month	Volume Per Collection (Cu. Yd.)	Cost Per Cu. Yd.
135	30	6	0.75
40	30	1	1.33
85	12	6	1.18
145	24	8	0.76
122	20	6	1.02
210	24	6	1.46
145	24	6	1.01
75	9	8	1.04
108	14	8	0.96
183	26	1	7.04
52	12	4	1.08
50*	No data	No data	No data
0+	20	15	0
400	30	12	1.11
45	26	2	0.87
125	52	4	0.60
0	10	8	0

* Hospital hauls waste in its own trucks.
+ Municipality hauls waste at no charge.

TABLE 4.3

COSTS OF HAULING
UNTREATED WASTE FROM HOSPITALS

Hauling Cost Per Month	Frequency of Collection Per Month	Volume Per Collection (Cu. Yd.)	Cost Per Cu. Yd.
560	24	28	0.83
540	60	16	0.56
135	24	6	0.94
106	16	6	1.10
1,695*	30	18	3.14

* Hospital hauls waste in its own trucks.

TABLE 4.4

COSTS OF HAULING
PULPED WASTE FROM HOSPITALS

Hauling Cost Per Month	Frequency of Collection Per Month	Volume Per Collection (Cu. Yd.)	Cost Per Cu. Yd.
128	24	3	1.78
165	21	8	0.98
900	12	40	1.88
64	12	32	0.17
90	60	1	1.50
240	12	14	1.43

CHAPTER V

COMPARISON OF SYSTEMS THROUGH REDUCED COST FUNCTIONS

5.1 Introduction

Usually a decision maker wants to compare a minimum number of parameters for alternative systems, which requires that the less important variables be suppressed and the cost functions be expressed in terms of the fewer, but more important variables. Where costs of alternative systems differ significantly over the range of the parameters' values, the cost differences can still be preserved and their relative rank ordering maintained even after a large number of the less important variables have been suppressed. However, when the cost differences of alternative systems are less significant, fewer variables can be suppressed so that simplifying the cost function necessitates including a larger number of variables to preserve the rank ordering of the alternative systems.

In designing hospital solid waste handling systems, the number of beds is the most frequent reference parameter used by the hospital administrators, management, planners and architects, and other members of the design team. Using the number of beds as the only input parameter simplifies comparisons between alternate systems. This chapter compares alternative systems, retaining only the number of beds as an explicit independent variable, while assigning average values current in real life systems to the other variables. When alternative systems did not differ significantly in their costs based on the typical values of the suppressed parameters, additional parameters are included explicitly in the list of independent variables in order to better discriminate between systems. The simplified cost functions which retain fewer independent variables will be called "reduced cost functions" derived from the cost functions developed in Chapter IV.

The development of reduced cost functions is more valid for the systems in the collection phase because parameter values are more stable in different environments during that phase than in the treatment phase.

Because in-hospital pulping of waste adds an extraordinary expense to any system of in-hospital waste collection, eliminating that option from an evaluation of alternative in-hospital systems allows better differentiation of systems with comparable costs. Therefore, the comparisons here have been carried out in two stages. The first stage compares alternative collection systems, and the second stage compares different treatment, hauling, and disposal systems exclusive of pulping.

5.2 Comparison of Systems in the Collection Phase

Figure 5.1 compares the annual equivalent costs of three collection systems (manual, gravity-manual, and gravity-pneumatic) using the number of beds as the only explicitly included independent variable. The waste generation rate, assumed to be 6.8 pounds per bed per day which corresponds to 8.5 pounds per patient per day at 80 percent occupancy, is typical of general hospitals as already shown in Chapter III. Other parameters have been given average typical values.

Over the bed capacity range (< 100 to 1000 beds) considered, the gravity-pneumatic and the manual systems are significantly more

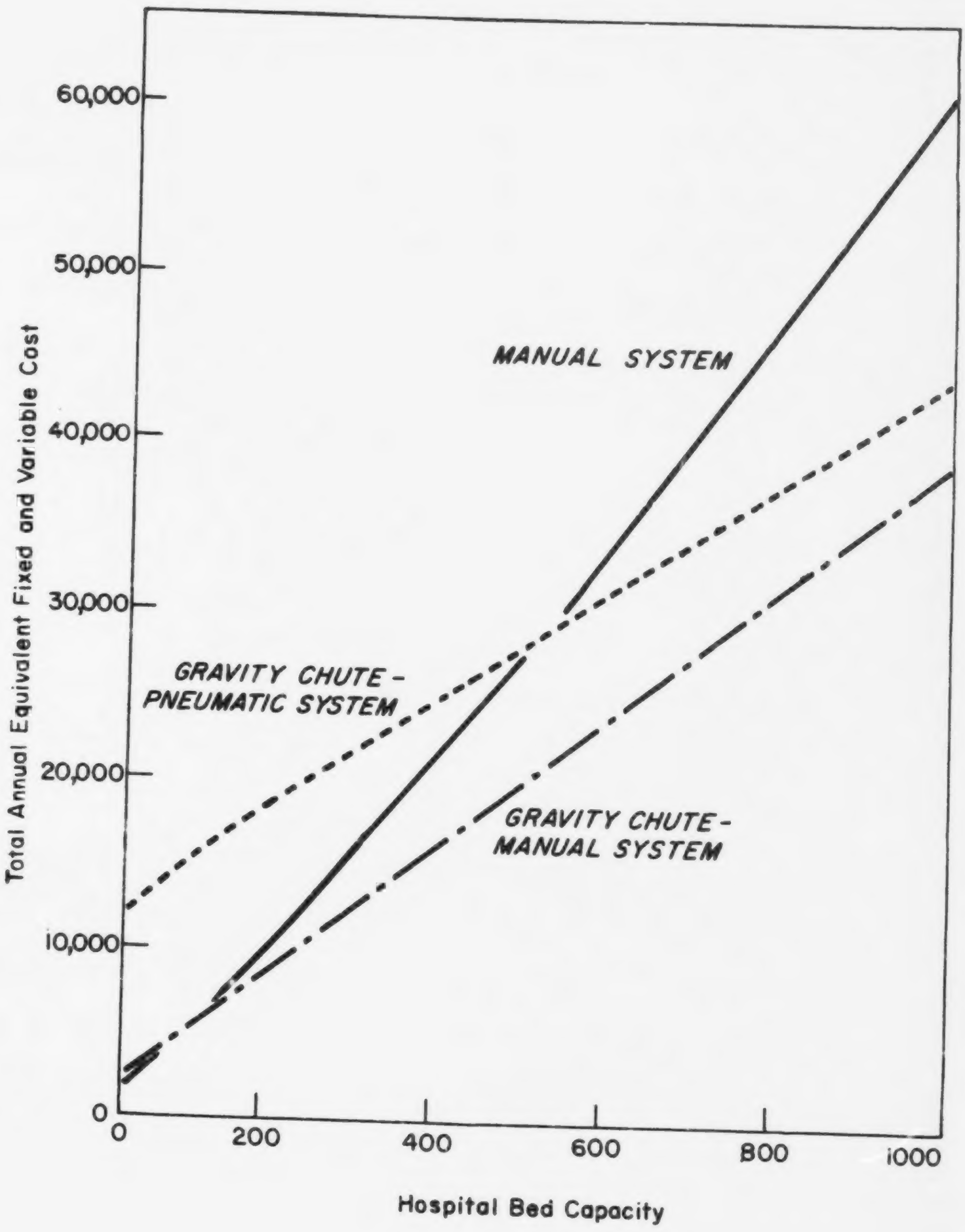

Figure 5.1 Showing total annual equivalent costs for the three collection systems for hospitals of various bed capacities.

expensive than the gravity chute-manual systems. For the purposes of this study, a system is "significantly" more expensive than another system if the cost difference of the two systems is 20 percent or more of the cost of the less expensive system. The gravity-pneumatic system is significantly more expensive than the manual system only up to a bed capacity of 400. The manual system becomes significantly more expensive than the gravity-pneumatic system beyond a bed capacity of 700. For hospitals having between 400 and 700 beds, the two systems are not significantly discriminated, but the gravity-pneumatic system is slightly more expensive up to 550 beds and the manual system is slightly more expensive beyond 550 beds.

To better discriminate between the costs of the gravity-pneumatic and the manual systems over the range of 400 to 700 beds, the number of floors in the hospital building must be included as an additional independent variable.

Figures 5.2 to 5.5 show cost curves drawn against the number of floors in hospitals with bed capacities of 400, 500, 600 and 700 beds. The curve in Figure 5.6, derived from the previous curves, divides the plane formed by the number of beds and the number of floors into two regions where the gravity-pneumatic system is less expensive in one region and the manual system less expensive in the other.

To determine at what rate of waste generation, if any, the gravity-pneumatic system becomes more economical than the gravity-manual system, cost curves are drawn for 400, 500, and 600 bed hospitals and with different waste generation rates and are shown in Figures 5.7, 5.8 and 5.9 respectively. The curve in Figure 5.10, derived from these

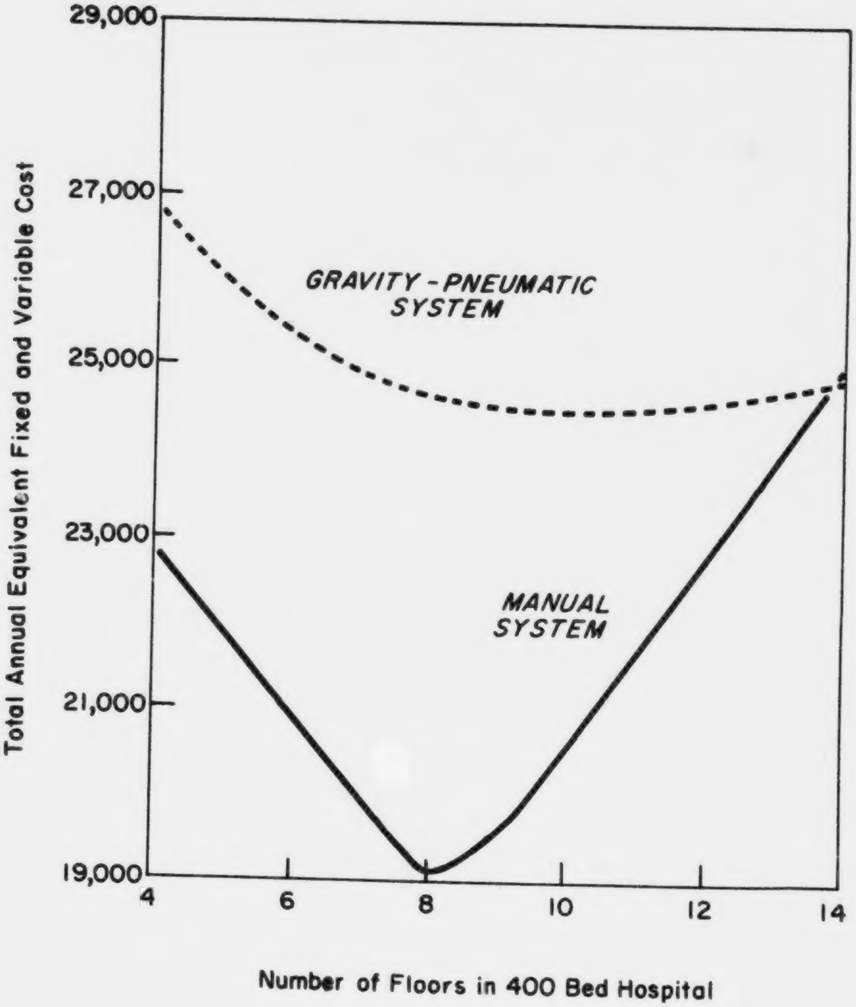

Figure 5.2 Showing total annual equivalent costs of gravity-pneumatic and manual systems for a 400 bed hospital with varying number of floors in the hospital building.

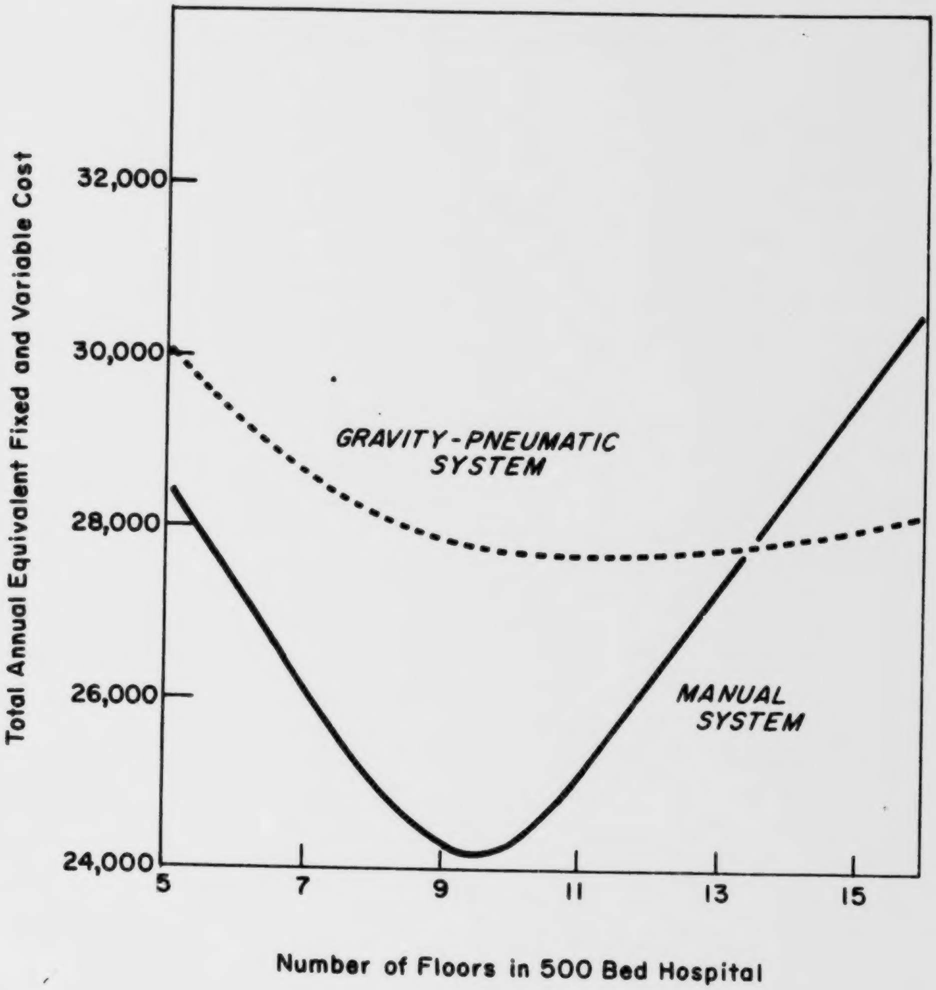

Figure 5.3 Showing total annual equivalent costs of gravity-pneumatic and manual systems in a 500 bed hospital with varying number of floors in the hospital building.

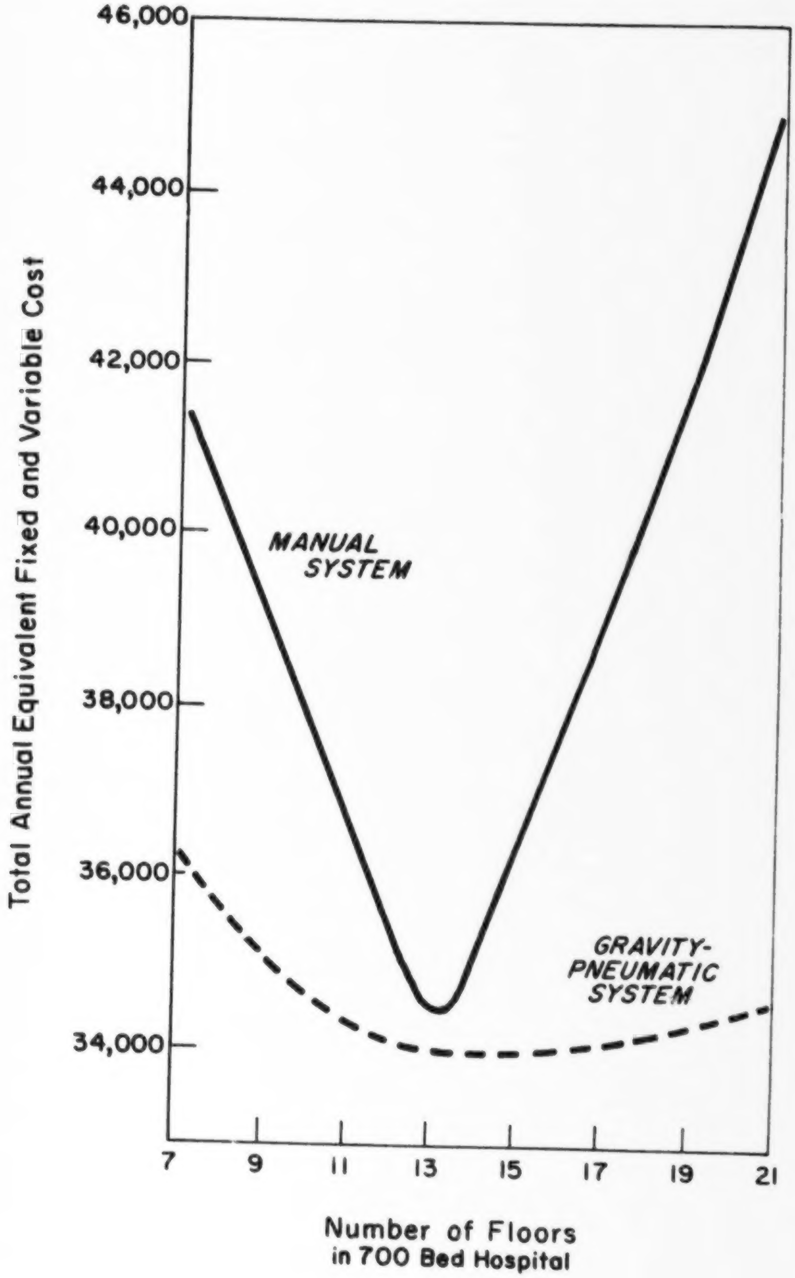

Figure 5.5 Showing total annual equivalent costs of gravity-pneumatic and manual systems in a 700 bed hospital with varying number of floors in the hospital building.

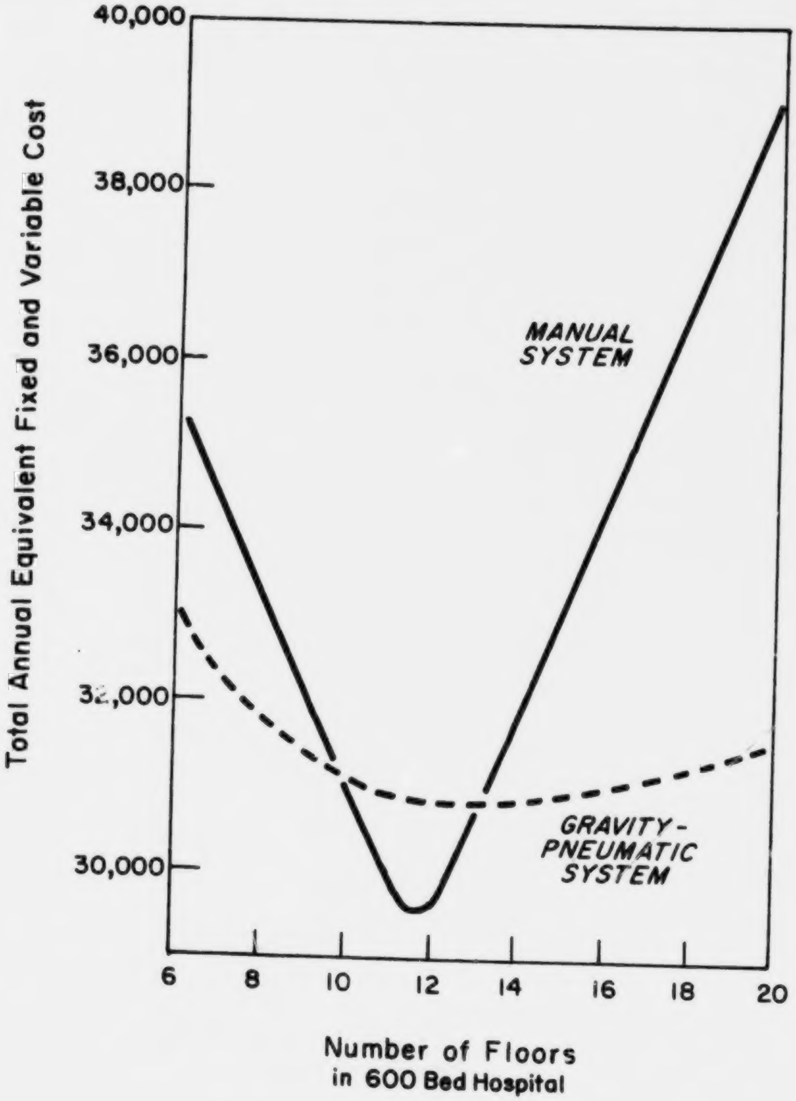

Figure 5.4 Showing total annual equivalent costs of gravity-pneumatic and manual systems in 600 bed hospital with varying number of floors in the hospital building.

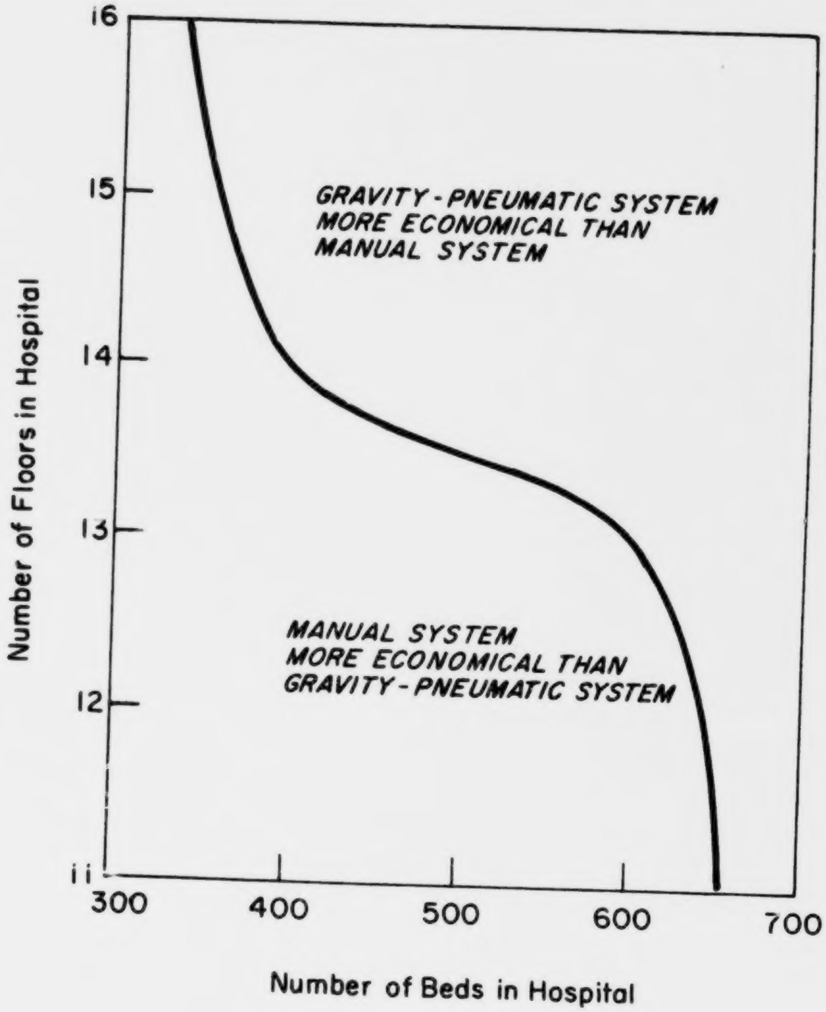

Figure 5.6 Division of the plane formed by the number of beds and the number of floors in a hospital into two regions; gravity - pneumatic system being economical in one and manual system being economical in the other.

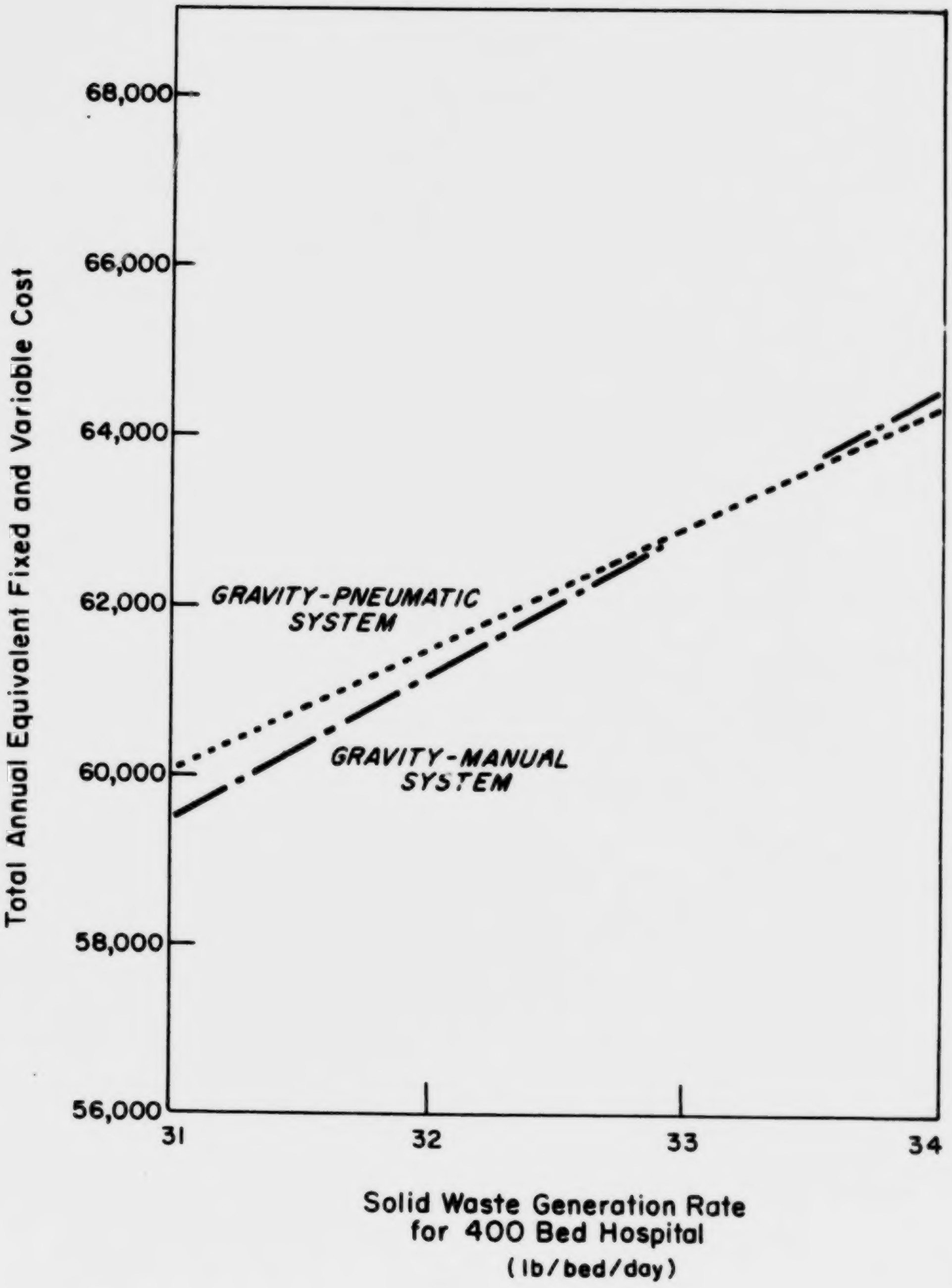

Figure 5.7 Showing total annual equivalent costs of gravity-pneumatic and gravity manual systems against various waste generation rates for a 400 bed hospital.

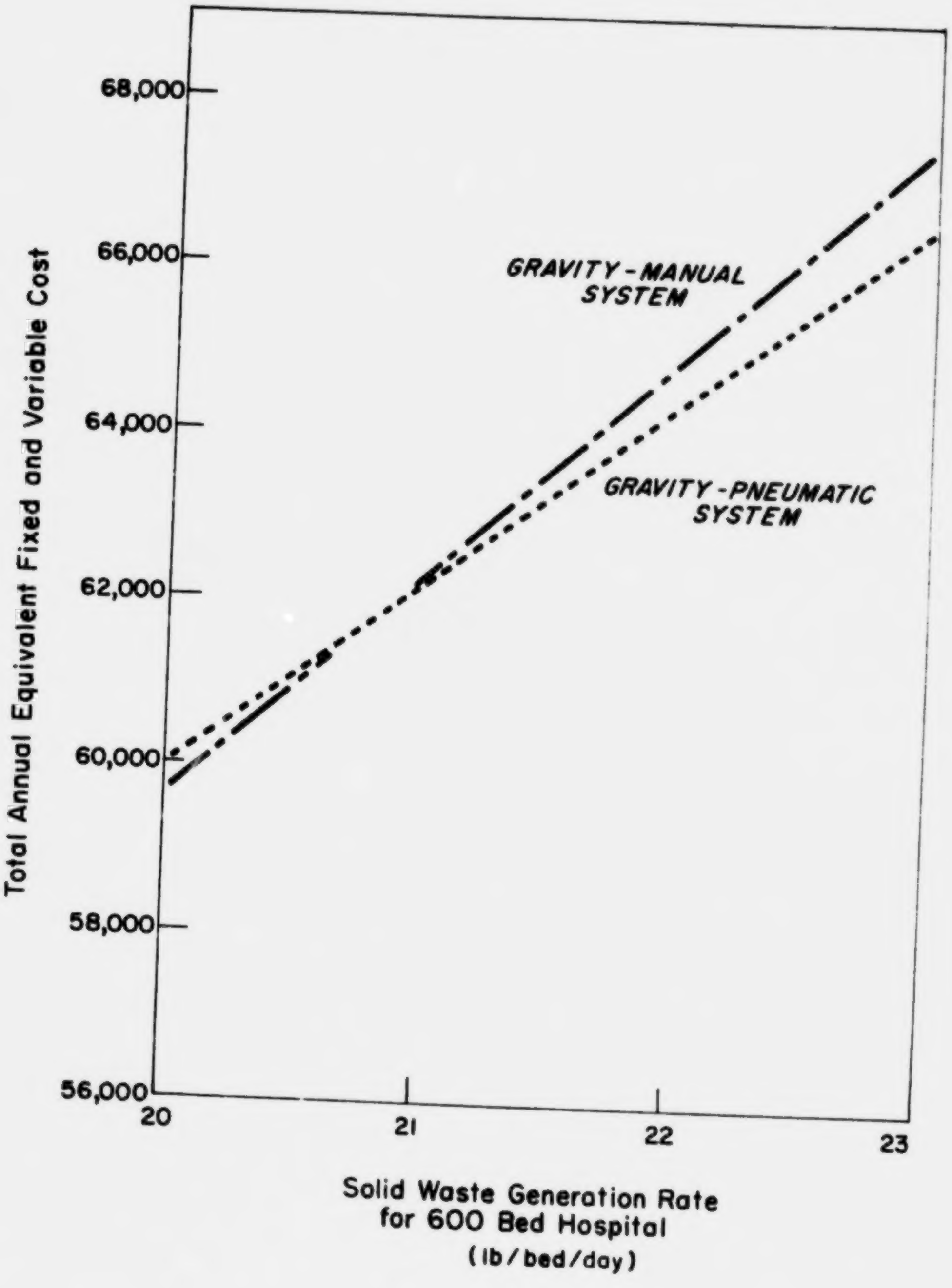

Figure 5.8 Showing total annual equivalent costs of gravity-pneumatic and gravity-manual systems against various waste generation rates for a 600 bed hospital.

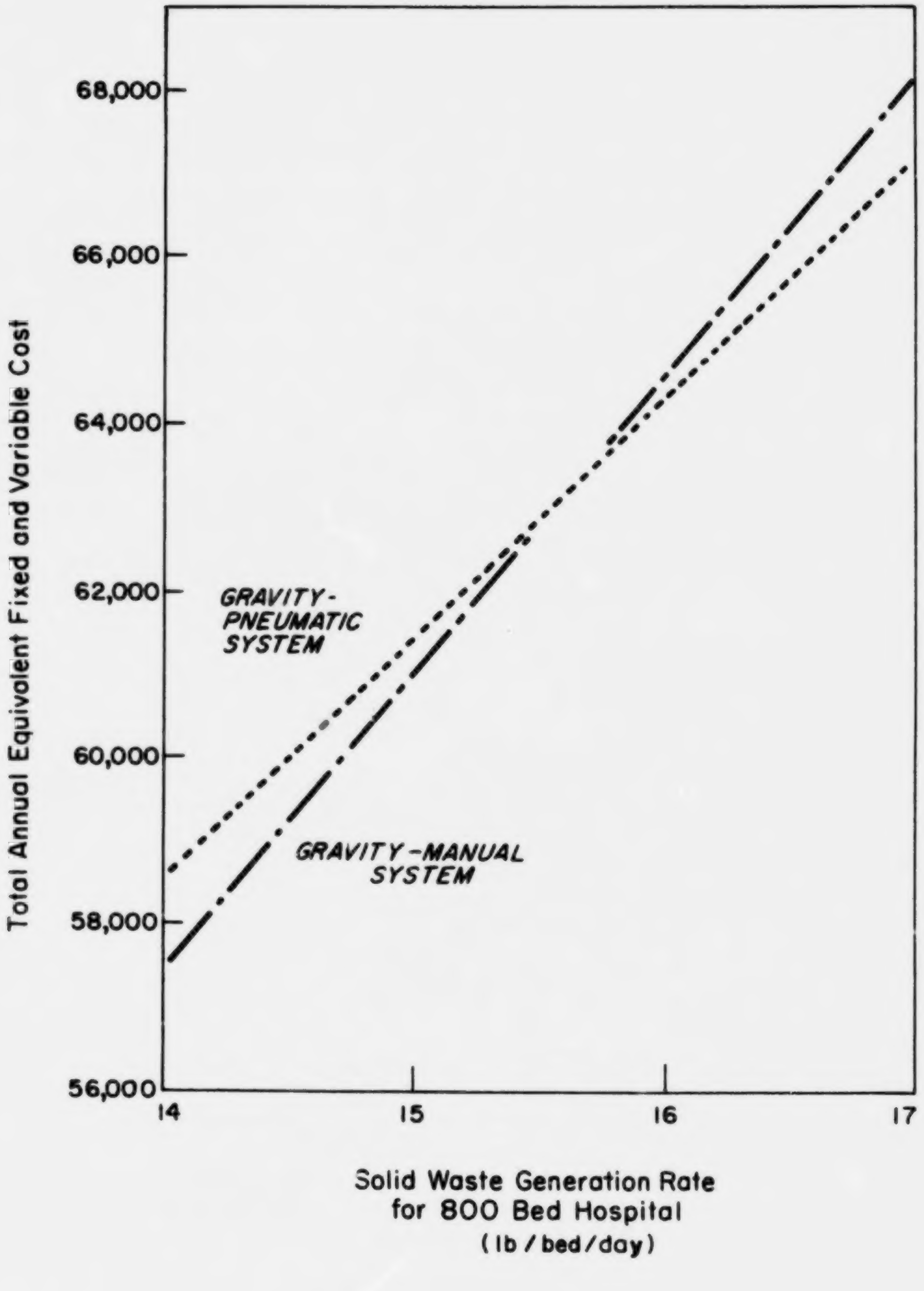

Figure 5.9 Showing total annual equivalent costs of gravity-pneumatic and gravity-manual systems against various waste generation rates for a 800 bed hospital.

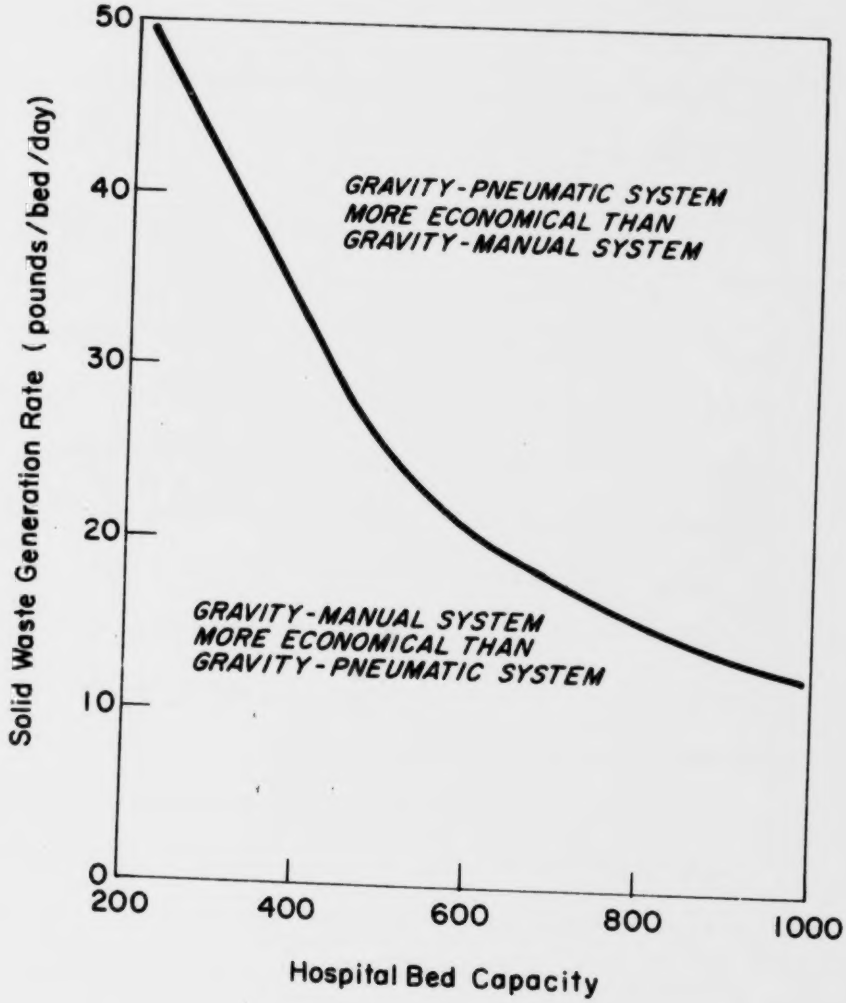

Figure 5.10 Division of the plane formed by the number of beds and the waste generation rate into two regions; gravity-pneumatic system being economical in one and gravity-manual system being economical in the other.

curves, divides the plane formed by the number of beds and the waste generation rate into two regions where the gravity-pneumatic system is less expensive in one and the gravity-manual system less expensive in the other.

5.3 Comparison of Systems in the Treatment, Hauling and Disposal Phase

Reduced cost curves for the systems in the treatment phase, with and without giving separate treatment to infectious waste, are shown in Figures 5.11 and 5.12. These curves compare the costs of incineration, hauling and disposal; compaction, hauling and disposal; and loose hauling and disposal of waste with the number of beds as the only independent variable. In deriving the curves, it is assumed that pathological waste would be incinerated in a small crematory, and since the cost of such a practice is similar for the three systems, it is not included in the cost curves.

When infectious waste is not treated separately in the compaction and loose hauling systems, incineration of all waste appears to be significantly more expensive than the other two systems at all bed capacities. Loose hauling and disposal appears to be significantly less expensive than compaction, hauling and disposal for hospitals with capacities of less than 300 beds and significantly more expensive when hospital capacities exceed 500 beds.

When infectious waste is incinerated separately in the compaction and loose hauling systems, loose hauling and disposal with separate incineration of infectious waste is significantly less expensive than the other two systems for hospitals with capacities of less than 250 beds.

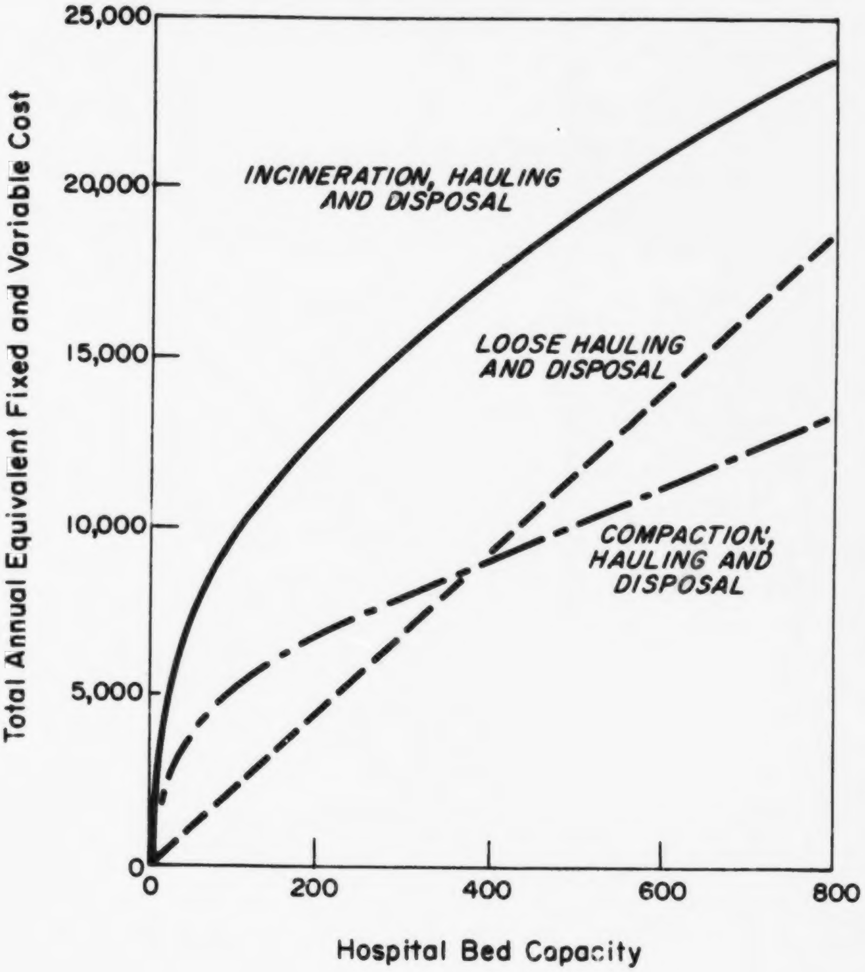

Figure 5.11 Showing total annual equivalent costs for three systems in the treatment and disposal phase for hospitals of various bed capacities, assuming that infectious waste receives no special treatment.

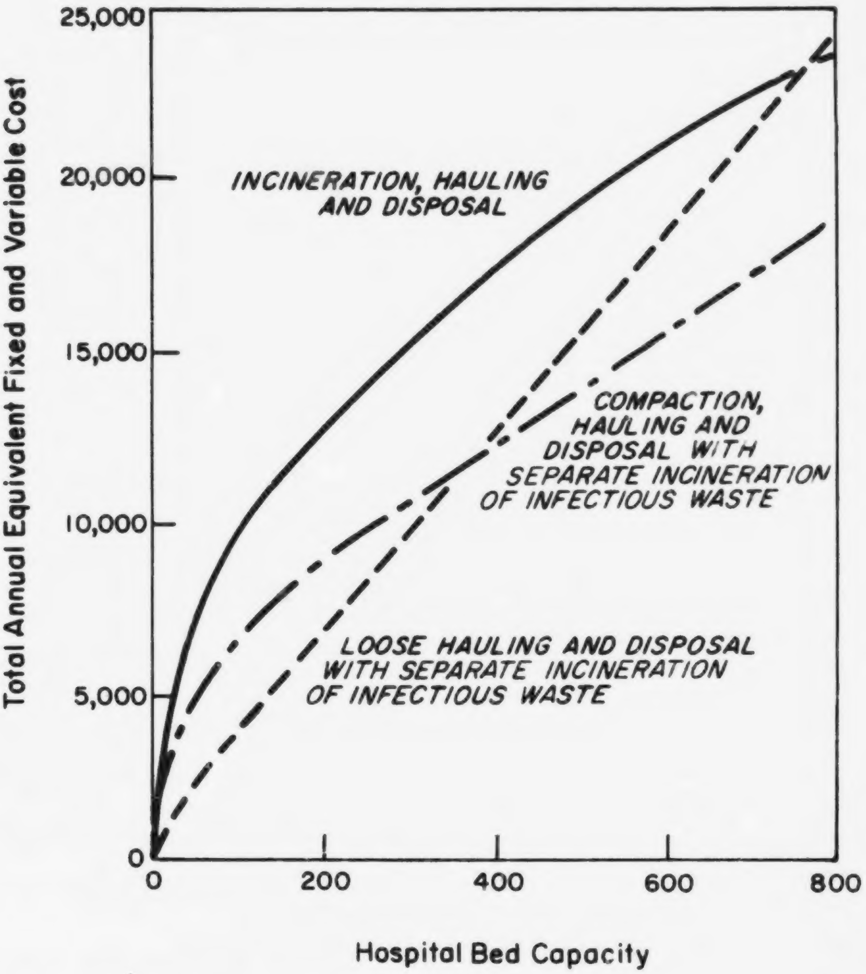

Figure 5.12 Showing total annual equivalent costs for three systems in the treatment and disposal phase for hospitals of various bed capacities, assuming that infectious waste is incinerated separately when compaction or loose hauling systems are used.

For hospitals with more than 500 beds, compaction, hauling and disposal with separate incineration of infectious waste becomes significantly less expensive. Incineration, hauling and disposal of all waste is significantly more expensive than the other two systems until the bed capacity reaches about 500 beds. For hospitals with more than 950 beds, loose hauling and disposal with separate incineration of infectious waste is significantly more expensive than incineration, hauling and disposal of all waste.

CHAPTER VI

STUDY OF SCOPE OF CENTRALIZATION

6.1 Introduction

Several economies may be realized by centralizing certain waste handling operations for a number of hospitals. For example, a group of contiguous hospitals could economize by centralizing internal waste collection by using a common pneumatic tube system, waste collection and hauling from hospital premises, or waste incineration. Of these possibilities, centralized incineration seems to be the most promising way to economize. This chapter studies the scope of centralized incineration among Twin City area hospitals. The model developed for the Twin City area could also be applied to other metropolitan areas.

In addition to the economic advantages, centralized incineration offers other advantages, such as reduced emissions through improved incineration operations, simplified monitoring for the regulatory agencies, and more flexibility and reliability of operations.

Centralized incineration offers economies in both the capital and operating costs. Economies in the costs of land and building structure result from the proportionately smaller land and building structure requirements; moreover, less expensive land can be utilized for the central incinerator. More efficient use of the equipment offers economies in the equipment cost. Operating costs decrease because of the reduced manpower requirements to operate the centralized incinerator. Estimated economies of scale for the various cost components were derived from the opinions of several knowledgeable people in real estate and hospital management and by using the cost functions for incineration derived in Chapter IV. If Z denotes the plant capacity, and C_1, C_2, and C_3 are the corresponding land and building structure cost, equipment cost, and operating cost respectively, the economies of scale may be represented by:

$$C_1 = A_1 Z^{0.8}$$
$$C_2 = A_2 Z^{0.87}$$
$$C_3 = A_3 Z^{0.5}$$

where A_1, A_2, and A_3 are constants.

The only cost which off-sets the economies available from centralized incineration is the higher cost of transporting waste from hospitals to the centralized plants. The total cost of centralized incineration for several hospitals will depend on the number of incinerator plants, their locations, their capacities, and routing of waste from hospitals to plants.

6.2 Mathematical Formulation of the Problem

Assuming that the sites for incineration are to be chosen from a predetermined list of potential sites, the problem may be formulated as a linear programming problem with fixed costs. Two alternative formulations are given here. The first formulation assumes that every potential site has an associated fixed plant capacity and, consequently, a constant fixed cost necessitating decisions about 1) which sites to pick for the centralized incineration plants, and 2) which hospitals to assign to each plant site. In the second formulation, the capital cost of a plant is a step function of the plant capacity. In addition to the decisions involved in the first formulation, the second formulation also involves a decision about the capacities of the plants. The objective of both formulations is to minimize the sum of variable costs and amortized plant and equipment costs.

6.2.1 Formulation 1

Let:

n = number of hospitals considered for centralization

i = index for hospitals; $i = 1,2,\ldots, n$

m = number of potential incinerator plants

j = index for incinerator plants; $j = 1,2,\ldots, m$

V_j = fixed plant capacity of plant j in tons per year (assumed to be given)

F_j = fixed cost associated with plant j

d_{ij} = distance of hospital i from plant j in miles

d_j = distance of plant j from the nearest available landfill in miles

C_{ij} = annual variable cost of disposing of waste from hospital i through plant j. This cost consists of the following three components:

(i) cost of transporting waste from the hospital to the plant;

(ii) cost of treating the waste at the plant; and

(iii) cost of transporting treated waste from the plant to the landfill.

t_{ij} = transportation cost per ton from hospital i to plant j, which may be taken as $v + ud_{ij}$ where v is the fixed cost per ton for a waste pickup at a hospital and u is the variable cost per ton per mile for transporting waste

a_j = treatment cost per ton at plant j

t_j = transportation cost per ton from plant j to the landfill, which may be taken as $v' + ud_j$ where v' is the fixed cost per ton for a pickup at an incineration plant and u is the variable cost per ton per mile for transporting waste

P = fraction of waste left after incineration

Q_i = amount of waste in tons per year to be treated from hospital i

Then the annual variable cost of disposing of waste from hospital i through plant j can be expressed as:

$$C_{ij} = (t_{ij} + a_j + Pt_j)\, Q_i \tag{1}$$

Mathematically the problem is to minimize the total sum of variable and fixed costs for the incinerator plants expressed by the formula:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij}\, X_{ij} + \sum_{j=1}^{m} F_j Y_j \tag{2}$$

by finding Y_j's and X_{ij}'s subject to the following conditions:

$$Y_j = \begin{cases} 1, & \text{if plant j is built} \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

$$X_{ij} = \begin{cases} 1, & \text{if waste from hospital i disposed of through plant j} \\ 0, & \text{otherwise} \end{cases} \tag{4}$$

$$\sum_{j=1}^{m} X_{ij} = 1 \quad \text{for } i = 1,2,\ldots, n \tag{5}$$

$$\sum_{i=1}^{n} Q_i X_{ij} \leq V_j Y_j \quad \text{for } j = 1,2,\ldots, m \tag{6}$$

Equation (5) specifies that all the waste from each hospital is assigned to one of the plants. Inequality (6) specifies that the capacity of the incineration plants is not exceeded and that no hospital is assigned to a site unless a plant exists there.

6.2.2 Formulation 2

In this formulation, the fixed cost of a plant is assumed to be a step function of plant capacity. Different treatment costs per ton are assumed over different capacity ranges. Let the capacity V (in tons per year) be divided into p ranges (V_0 to V_1, V_1 to V_2,..., V_{p-2} to V_{p-1}, V_{p-1} to V_p) and let these p ranges be the same for all plants. Let:

n = number of hospitals considered for centralization

i = index for hospitals; $i = 1,2,\ldots n$

m = number of potential incinerator plants

j = index for incinerator plants; $j = 1,2,\ldots, m$

k = index of capacity range V_{k-1} to V_k; $k = 1,2,\ldots, p$

F_{jk} = fixed cost of plant j over capacity range V_{k-1} to V_k

a_{jk} = treatment cost per ton at plant j over capacity range V_{k-1} to V_k

d_{ij} = distance of hospital i from plant j in miles

d_j = distance of plant j from the nearest available landfill in miles

t_{ij} = transportation cost per ton from hospital i to plant j, which may be taken as $v + ud_{ij}$ where v is the fixed cost per ton for a waste plickup at a hospital and u is the variable cost per ton per mile for transporting waste

t_j = transportation cost per ton from plant j to the landfill, which may be taken as $v' + ud_j$ where v' is the fixed cost per ton for a pickup at an incineration plant and u is the variable cost per ton per mile for transporting waste

P = fraction of waste left after incineration

Q_i = amount of waste in tons per year to be treated from hospital i

Mathematically the problem is to minimize the total sum of variable and fixed costs for the incinerator plants expressed by the formula:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} X_{ij}(t_{ij} + Pt_j)Q_i + \sum_{i=1}^{n}\sum_{j=1}^{m} X_{ij}(\sum_{k=1}^{p} A_{jk}Y_{jk})Q_i$$
$$+ \sum_{j=1}^{m}\sum_{k=1}^{p} F_{jk}Y_{jk} \qquad (1)$$

by finding Y_{jk}'s and X_{ij}'s subject to the following conditions:

$$Y_{jk} = \begin{cases} 1, \text{ if plant } j \text{ is built and operated at a capacity range } V_{k-1} \text{ to } V_k \\ 0, \text{ otherwise} \end{cases} \qquad (2)$$

$$X_{ij} = \begin{cases} 1, \text{ if waste from hospital } i \text{ disposed of through plant } j \\ 0, \text{ otherwise} \end{cases} \qquad (3)$$

$$\sum_{j=1}^{m} X_{ij} = 1 \text{ for } i = 1,2,\ldots, n \qquad (4)$$

$$\sum_{k=1}^{p} Y_{jk} \leq 1 \text{ for } j = 1,2,\ldots, m \qquad (5)$$

$$\sum_{i=1}^{n} X_{ij}Q_i \leq \sum_{k=1}^{p} V_kY_{jk} \text{ for } j = 1,2,\ldots, m \qquad (6)$$

Equation (4) specifies that each hospital is assigned to only one plant. Inequality (5) specifies that a plant can only be operated at one capacity range. Inequality (6) specifies that the amount of waste brought to a plant does not exceed its capacity.

6.3 Solution to Fixed Charge Problems

Problems of the type formulated in the preceding two sections, where some fixed charge is associated with the opening of each plant, are known as fixed charge problems. Such problems cannot be solved by standard linear programming techniques due to the step nature of the fixed costs. Alternate approaches described in the literature to solve this problem are heuristic methods[2,21], integer programming techniques[1,2], and branch and bound techniques[9,22,30].

6.4 Centralized Incineration for the Twin City Area Hospitals

The model developed under formulation 1 for centralized incineration has been applied to Twin City area hospitals, based on data available from 28 of the 37 hospitals in the Twin City area (see Table 6.1). Figure 6.1 shows that most of the 28 hospitals are concentrated around the two downtown areas of Minneapolis and St. Paul, many of them located in close proximity. Hospitals located in outlying counties were not considered for centralized incineration. Taking into account land availability, cost and zoning restrictions, four sites were chosen as potential locations for the centralized incinerators. The nearest landfill to each of the incinerator sites was identified. Figure 6.2 shows the location of the four potential sites in relation to the hospitals and sanitary landfills in the area.

Information on distances of the hospitals from the various sites, distances of the sites from the nearest landfills, and amounts of waste required to be treated from the hospitals was obtained from a variety of sources. The pertinent data in the problem formulations are as follows:

n = 28 = number of hospitals considered for centralization

m = 4 = number of potential incinerator plants

v = 5.5 dollars per ton* = fixed cost for waste pickup at a hospital

u = .24 dollars per ton per mile* = variable cost for transporting waste

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*The estimates for v and u were obtained from a solid waste study[34] by Truitt, Leibman and Kruse

TABLE 6.1

SUMMARY OF INFORMATION COLLECTED FROM 28 TWIN CITY AREA HOSPITALS CONCERNING INCINERATION, COMPACTION AND HAULING OF HOSPITAL SOLID WASTE

	Incineration				Compaction		Hauling					
Hospital	Solid wastes incinerated	Capital cost	Utility costs/month	Operation manhours/month	Capital cost	Leasing cost/month	Container size (cu.yd.)	Frequency of hauling	Hauling cost/load	Total monthly hauling cost	Hauler	Landfill
1	Path.[a]	N/A	N/A	30	N/A	$355	42	1/wk	$50	$572	A	1
2	Path.	$1,000	$10	75	$13,000	N/A	40	1/wk	$53	$230	B	2
3	C & P[b]	$15,000	$20	210	N/A	No charge	10	3-4/wk	$25	$452	B	3
4	C & P	$5,000	$5	60	N/A	N/A	N/D	2/wk	N/D	$75	C	3
5	Path.[a]	N/A	N/A	15	$500[g]	$370	40	1/2.5 wk	$45	$448	B	2
6	None[c]	N/A	N/A	N/A	N/A	N/A	2(8),2(6)[j]	6/wk	N/D	$560	D	3
7	C & P	$16,000	$750	210	N/A	N/A	4(1.5)	7/wk	N/D	$135	A	1
8	None	N/A	N/A	N/A	$2,100	N/A	N/D	3/wk	N/D	$192[k]	**	3
9	None	N/A	N/A	N/A	N/A	No charge	20,24,2,2(1)	1/wk	$35	$315[l]	E	4
10	Path.	$2,600	Neg.	30	$5,900	N/A	40	2/wk	$50	$458	B	2
11	Combus.	$6,000	Neg.	120	N/A	N/A	1	7/wk	N/D	$40	A	7
12	None[c]	N/A	N/A	N/A	$5,900	N/A	40	1/wk	$50	$217	B	2
13	P & Iso.[d]	$11,500	$200	180	N/A	N/A	2(8),12	2/day	N/D	$540	F	5
14	C & P	$60,000[f]	$250	240	N/A	$185	40	5-6/mth	$50	$460	B	2
15	C & P	$3,707	Neg.	75	N/A	N/A	4(1.5)	3/wk	N/D	$85	B	3
16	P & Iso.	$7,500	$10	60	N/A	N/A	6	6/wk	N/D	$135	B	3
17	None[c]	N/A	N/A	N/A	$4,300	$60[i]	40	1/wk	$45	$255	B	2
18	None	N/A	N/A	N/A	N/A	*	10	1-2/wk	*	$120	B	3
19	None	N/A	N/A	N/A	$12,800[h]	N/A	4(1.5)	7/wk	N/D	$560	A	7
20	C & P	$18,150	$10	75	N/A	N/A	2(1),6	6/wk	N/D	$145	A	1
21	None	N/A	N/A	N/A	N/A	N/A	6	4/wk	N/D	$106	B	3
22	Path[a]	N/A	N/A	30	N/A	$270	40	2/wk	$45	$660	B	3
23	None	N/A	N/A	N/A	N/A	*	5(2)	6/wk	*	$754	D	3
24	C & P	$7,000	$10	270	N/A	N/A	6	5/wk	N/D	$122	B	3
25	C & P	$13,000	$50	403	N/A	N/A	4(1.5)	6/wk	N/D	$210	B	2
26	C & P	$21,000	$700	240	N/A	N/A	6	6/wk	N/D	$145	G	3
27	C & P	N/D	N/D	15	N/A	N/A	1.5	1/wk	N/D	$18	H	[illegible]
28	None[e]	N/A	N/A	N/A	N/A	N/A	18	1/day 2/day(path.)	N/D	$1,695	**	8

[a] Placed in boiler

[b] Combustible and pathological

[c] Path. taken to another hosp.

[d] Pathological and isolation

[e] Path. taken to offsite incin.

[f] Includes building construction

[g] Includes building modification

[h] Includes three compactors and four 1.5 cu.yd. containers

[i] Lease container

[j] Two 8 cu.yd. containers, two 6 cu.yd. contianers

[k] Estimated

[l] Rent two compactors

* Only total hauling costs available

** Haul in own truck(s)

N/A = Not applicable

N/D = No data

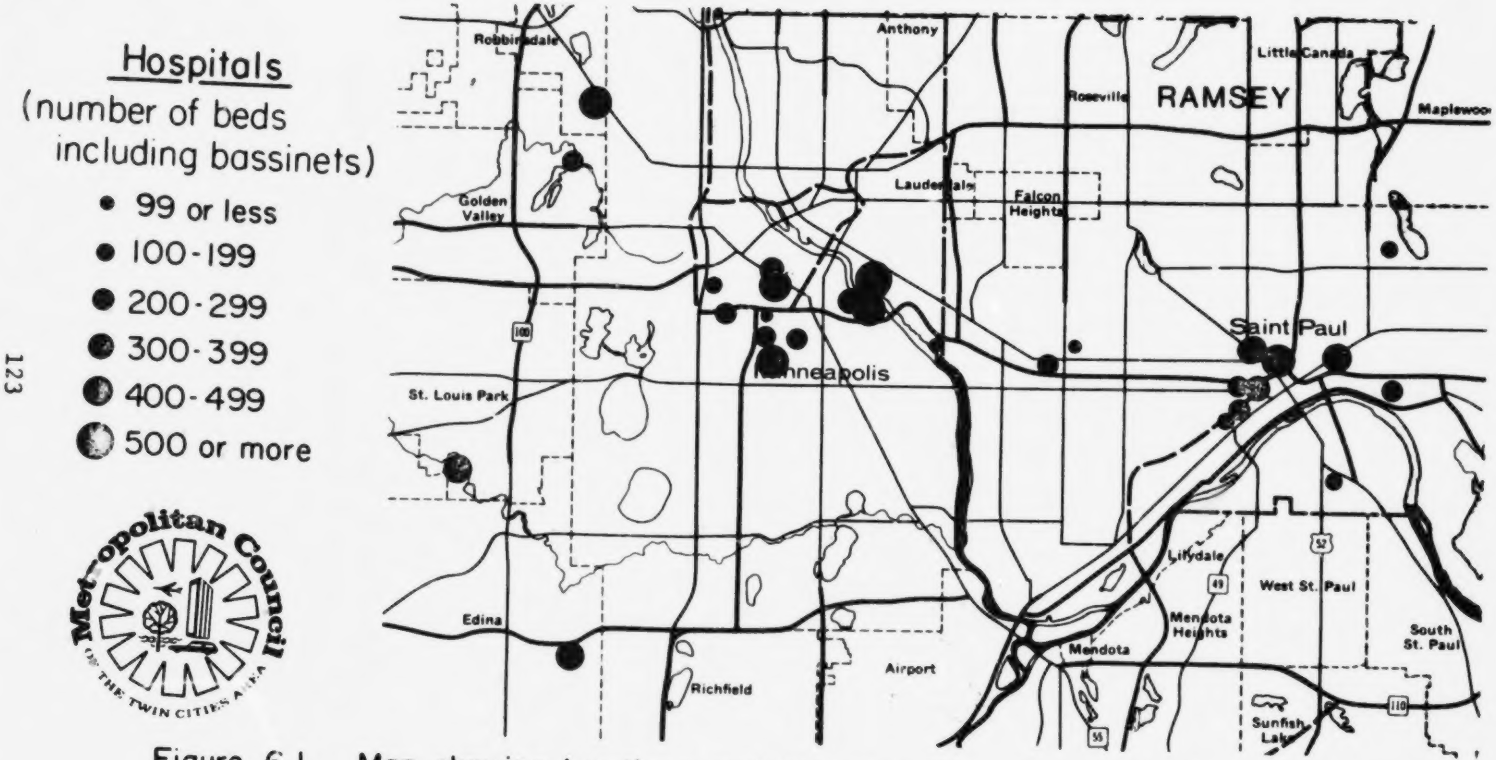
Hospitals
(number of beds including bassinets)
● 99 or less
● 100-199
● 200-299
● 300-399
● 400-499
● 500 or more
Metropolitan Council of the Twin Cities Area
Robbinsdale
Anthony
Roseville
RAMSEY
Little Canada
Maplewood
Lauderdale
Falcon Heights
Golden Valley
100
Saint Paul
Minneapolis
St. Louis Park
Lilydale
52
49
West St. Paul
Mendota Heights
Mendota
South St. Paul
Edina
Airport
Richfield
55
Sunfish Lake
110

Figure 6.1 Map showing locations and bed capacities of the 28 Twin City area hospitals considered for centralized incineration.

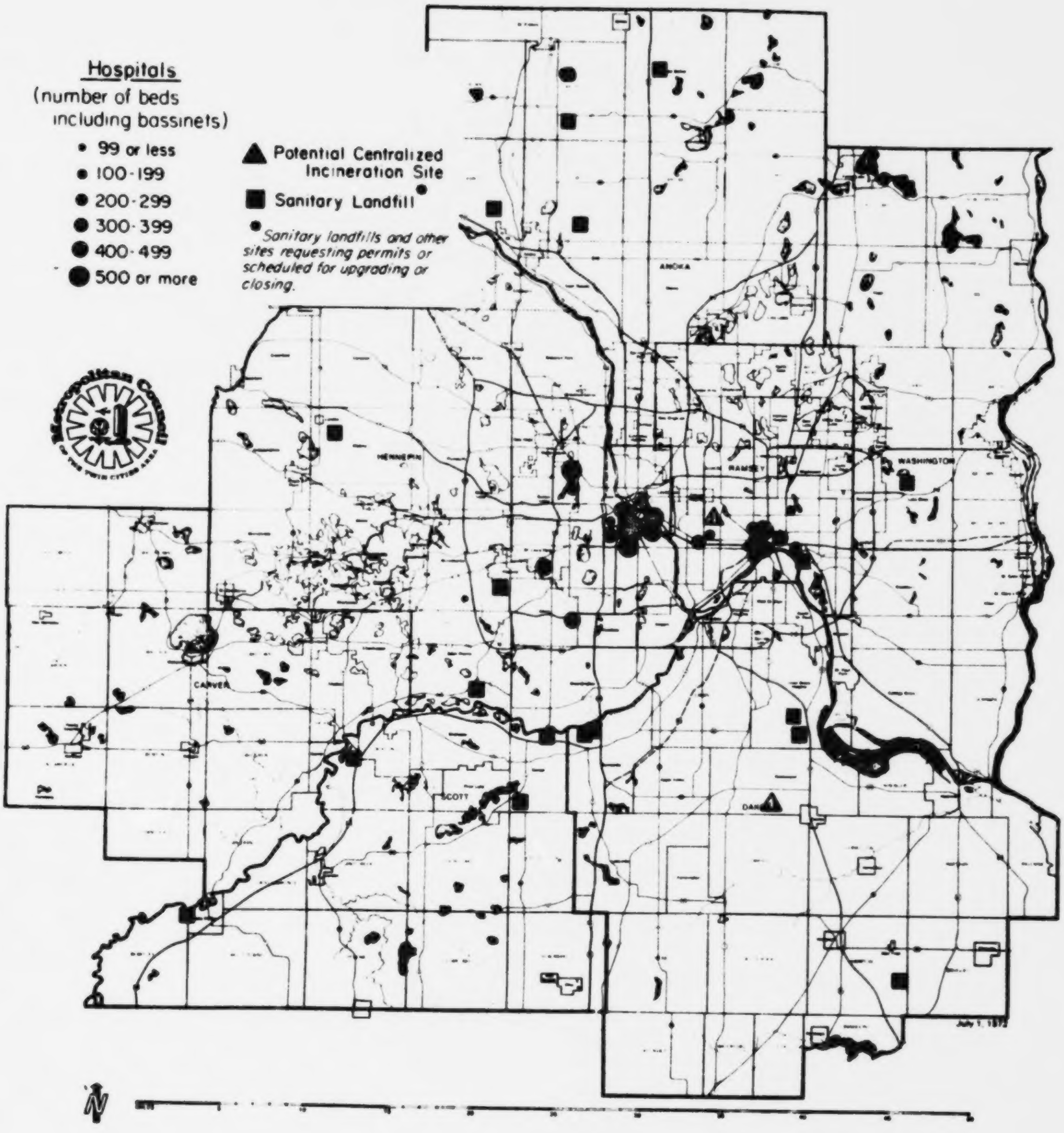
Hospitals
(number of beds including bassinets)
• 99 or less
● 100-199
● 200-299
● 300-399
● 400-499
● 500 or more
▲ Potential Centralized Incineration Site
■ Sanitary Landfill*
*Sanitary landfills and other sites requesting permits or scheduled for upgrading or closing.
ANOKA
HENNEPIN
RAMSEY
WASHINGTON
CARVER
SCOTT
DAKOTA
N

Figure 6.2 Map of the Twin City area showing the locations of the four potential centralized incinerator sites, the 28 hospitals considered for centralized incineration, and the sanitary landfills in the area.

d_{ij}'s given in Table 6.2

Q_i's given in Table 6.3

d_j's and F_j's given in Table 6.4

v' = 4 dollars per ton = fixed cost for incinerator residue pickup at a plant

a_j = 7 dollars per ton = treatment cost at plant j

P = .25 = fraction of waste left after incineration

6.4.1 Analysis and Results

Solving the problem requires selecting plant sites, then allocating hospitals to the plants to minimize the total annual equivalent cost of incineration and transportation from the hospitals to their respective landfill sites for the selected 28 hospitals. The annual equivalent cost includes the variable costs and the fixed costs duly amortized on an annual basis. Since the present problem is very small, an enumerative procedure was adopted for seeking the optimal solution. Only 15 combinations were considered in the selection of sites from the four potential incinerator sites; four possibilities of having only one plant to serve all the hospitals situated at one of the four sites, six possibilities of having two plants at any two of the four sites, four possibilities of having three plants at any three of the four sites, and one possibility of having a plant at each of the four sites. All 15 possibilities are listed in Table 6.5. Each possibility is identified by a four digit code where each digit is either 1 or 0; 1 when a particular plant site is chosen and 0 when it is not chosen. Thus, the possibility (1,1,0,0) corresponds to having plants at sites 1 and 2. Fixed cost, variable cost, and total cost of the best

TABLE 6.2

DISTANCES (d_{ij}) OF THE HOSPITALS FROM THE POTENTIAL INCINERATOR PLANTS

Hospital i	Distance (d_{ij}) in Miles from Hospital i to Plant j			
	j = 1	j = 2	j = 3	j = 4
1	25.0	14.0	3.0	8.0
2	22.0	16.0	8.0	3.5
3	21.5	16.0	7.0	4.0
4	22.0	16.5	8.0	4.0
5	25.5	14.0	3.0	8.0
6	24.0	13.5	1.5	6.0
7	25.0	22.5	11.0	6.0
8	24.0	16.0	13.5	6.0
9	28.0	15.0	5.0	10.0
10	24.5	13.0	2.5	7.5
11	25.0	14.0	2.5	7.0
12	23.0	13.5	2.0	7.0
13	30.0	20.0	9.0	12.5
14	24.0	13.5	2.0	7.0
15	22.5	14.5	4.0	2.0
16	22.5	17.5	10.0	6.0
17	24.5	14.0	2.5	7.5
18	23.0	14.5	4.5	1.5
19	28.5	15.5	5.0	10.5
20	24.0	14.5	3.0	7.0
21	20.0	17.5	10.5	7.0
22	21.5	16.5	9.0	5.0
23	21.5	16.0	7.0	4.0
24	22.0	16.5	8.0	4.0
25	24.0	13.5	1.5	6.0
26	21.0	16.0	8.0	3.5
27	23.0	14.0	2.5	4.0
28	24.5	13.0	0.8	5.5

TABLE 6.3

AMOUNTS (Q_i) OF WASTE TO BE TAKEN FROM THE HOSPITALS TO THE INCINERATOR PLANTS FOR TREATMENT

Hospital i	Amount of Waste (Q_i) in Tons/Year	Hospital i	Amount of Waste (Q_i) in Tons/Year
1	384	15	397
2	413	16	296
3	496	17	384
4	155	18	139
5	184	19	634
6	456	20	630
7	527	21	126
8	164	22	589
9	498	23	587
10	522	24	469
11	63	25	824
12	274	26	723
13	587	27	53
14	975	28	1,460

TABLE 6.4

ANNUAL AMORTIZED FIXED COSTS (F_j) OF INCINERATOR PLANTS AND THE DISTANCES (d_j) OF PLANTS FROM THE NEAREST AVAILABLE LANDFILL SITES

Plant j	Distances from Landfill (d_j) in miles	Annual Amortized Fixed Cost (F_j)
1	9	40,000
2	14	40,000
3	14	52,000
4	16	40,000

TABLE 6.5

SOLUTION TO CENTRALIZED INCINERATION PROBLEM
FOR TWIN CITY AREA HOSPITALS

Possibilities	Amortized Annual Fixed Costs (Dollars)	Annual Variable Costs (Dollars)	Annual Total Costs (Dollars)
(1,0,0,0)	40,000	258,000	298,451
(0,1,0,0)	40,000	235,629	275,629
(0,0,1,0)	52,000	299,965	252,965
(0,0,0,1)	40,000	208,165	$\boxed{248,165}$
(1,1,0,0)	80,000	234,206	314,206
(1,0,1,0)	92,000	200,965	292,965
(1,0,0,1)	80,000	208,165	288,165
(0,1,1,0)	92,000	200,965	292,965
(0,1,0,1)	80,000	208,165	238,165
(0,0,1,1)	92,000	197,800	289,800
(1,1,1,0)	132,000	200,965	332,965
(0,1,1,1)	132,000	197,965	329,965
(1,0,1,1)	132,000	197,965	329,965
(1,1,0,1)	120,000	208,165	328,165
(1,1,1,1)	172,000	297,965	369,965

solution corresponding to each possibility are given in Table 6.5. That table shows that minimum cost is $248,165 which is achieved by the possibility (0,0,0,1) i.e., having only one plant to serve all the hospitals and having it situated at site 4.

Cost estimates of each hospital individually incinerating on its own premises is $456,808. An estimated potential saving of $208,643 ($456,808 - $248,165) in the incineration and transportation cost results from centralization of the incineration operation. The thought of such a saving is very tempting!

CHAPTER VII

SUMMARY

In most hospitals today, facilities for handling solid waste are antiquated. The art of designing hospital solid waste handling systems has lagged behind the development of other operational systems in hospitals, due to the lack of awareness of the true importance and magnitude of the problem, lack of reliable data on the cost and performance of various waste handling systems and the lack of adequate criteria for evaluating alternative systems. This study attempts to develop a more rational basis for comparing hospital solid waste handling systems from a total system perspective which considers both operational costs and social costs. Because it is difficult to measure social costs, the approach adopted in the study is to prescribe minimal acceptable performance standards for the different waste handling systems and then compare the systems, which satisfy these standards on the basis of operational costs.

A preliminary, yet essential, step in developing a methodology for comparing hospital solid waste handling systems is the classification and quantification of waste. Using the data collected as part of the study "Hospital Solid Waste Disposal in Community Facilities"[18] supplemented by additional data obtained through questionnaires sent to hospitals surveyed in this previous study, a procedure has been developed to estimate the daily solid waste generation for a hospital, depending on its location, bed capacity, and use of single-use items.

The steps involved in developing the methodology for comparing systems are:

(i) identification of the stages involved in a total hospital waste handling system;

(ii) identification of alternative systems for the various stages;

(iii) prescribing minimal performance standards for the alternative systems; and

(iv) developing cost functions which relate the operational cost of the systems, which comply with the specified standards, to pertinent hospital parameters.

A decision tree is used to depict the stages and available alternatives at each stage of a total waste handling system. This approach provides a valuable tool for the decision-maker because at any stage, the choice among the alternative systems must be made while considering its implication on the total system.

With information obtained from the literature, brochures from manufacturers and contacts with hospitals throughout the country, a set of minimal performance standards for the different hospital solid waste handling systems is developed and expanded into a series of operation guidelines. These suggested operational procedures are designed to offer the decision-maker a preview of the total operation of a solid waste handling system prior to purchase and installation and to assist hospital personnel in developing guidelines for the operation of their particular system.

The importance of the cost functions is that they provide a means for comparing the overall costs of hospital solid waste handling systems which include not only the initial costs required to install the systems, but also the expenses involved to keep the systems operating. The cost functions also provide a means for identifying cost parameters, such as labor costs, utility costs and material costs, which are frequently overlooked when comparing costs of systems, but which contribute significantly to the overall cost.

The reader is cautioned about the use of the numerical values of the parameters given in the report. These values represent averages of cost and other information obtained during 1971-1972 from questionnaires to hospitals, information from the manufacturers of various kinds of equipment and by on-site observations in several hospitals. In order to provide the decision-maker with a means to evaluate the cost functions in terms of parameter values which reflect current equipment costs and characteristics of his particular hospital, a computer program has been developed which can accept varying values of the parameters.

Certain economies of scale may be possible through the centralization of certain waste handling operations for a number of hospitals. To investigate such potential economies, a model of a centralized incineration system is formulated and applied to the Twin City area hospitals. This preliminary investigation demonstrates that a considerable saving can be realized through centralized incineration as compared to having incineration performed by hospitals on an individual basis on the hospital premises.

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GLOSSARY OF VARIABLES

CHAPTER III. CLASSIFICATION AND QUANTIFICATION OF WASTE

A_j = set of distinctive types to be lumped in the jth category

a = constant term

$a_1, a_2, \ldots, a_6$ = coefficients of $x_1, x_2, \ldots, x_6$ respectively

$a', a_1', \ldots, a_6'$ = sample estimates of $a, a_1, \ldots, a_6$ respectively

j = index of the categories; $j = 1, 2, \ldots, s$

N = sample size (number of hospitals)

$p_1, p_2, \ldots, p_k$ = percentages of the k distinctive types which are to be grouped into s categories

$S_{a'}, S_{a_1'}, \ldots, S_{a_6'}$ = estimates of the standard deviations of $a', a_1', \ldots, a_6'$

$S_{y'}$ = standard deviation of y'

s = number of categories

U_j = percentages of the jth category

x_1 = total hospital census, including newborn, on the day the survey was performed

x_2 = number of surgical operations per year performed by a hospital

x_3 = number of out-patient visits per year

x_4 = number of hospital employees

x_5 = number of nurses in the training school

x_6 = number of meals served on the day the survey was performed

y = weight of solid waste in pounds per day

y' = estimate of y

CHAPTER IV. COST FUNCTIONS

Section 4.2.1 Manual System

A_i = area of the ith floor in square feet

A_{ij} = area of the jth section on the ith floor in square feet

a_1 = area of building space, in square feet, allocated for housing carts and containers

$(\frac{a}{p})^{I}_{y}$ = capital recovery factor

C = average wage rate per hour including overhead

C_1 = cost per container

C_2 = cost per cart

C_3 = annual rental cost per square foot of building space

C_4 = cost of one waste container liner

C_5 = electricity cost per kilowatt hour

d = distance from the elevator to the central storage location in feet. If there is more than one elevator, then d will be the average distance.

d_{ij} = distance of the jth section from the elevator on the ith floor in feet

E_1 = annual amortized elevator capital cost

E_2 = annual elevator maintenance cost

Em_1 = annual equivalent capital cost of a manual system

Em_2 = total annual operation cost of a manual system

Em_3 = annual labor cost of a manual system

Em_4 = annual cost of waste container liners used in a manual system

Em_5 = annual cost for the use of elevators for waste handling in a manual system

e = total cost per hour for using an elevator

F_i = frequency of waste collection per day on the ith floor

H = average number of hours an elevator is used per day

H_i = horizontal distance traveled for collection of waste on the ith floor

I = interest rate per year on the capital

i = index of the ith floor; $i = 1, 2, \ldots, N$

L_i = number of trips required to collect waste from the ith floor

N = number of floors in a hospital building

N_1 = number of containers in a manual system

N_2 = number of carts in a manual system

n_i = number of intermediate accumulation points on the ith floor from which waste is to be collected

n_{ij} = number of intermediate accumulation points in the jth section on the ith floor

P_i = perimeter of the ith floor in feet

T = standard time in hours per day

T_H = horizontal travel time in minutes per day

T_L = loading time of carts in minutes per day

T_N = normal time (average time for actually doing the work) in minutes per day

T_U = unloading time of carts in minutes per day

T_V = vertical travel time in minutes per day

t_e = normal time in man-minutes for emptying one lined waste receptacle. This includes the time required for the removal of a liner from the receptacle, placing the waste in the cart, and placing a new liner in the receptacle.

t_o = normal time in man-minutes for loading and unloading a cart into an elevator

t_r = normal time in man-minutes for removing one bag from a cart and placing it in a container at the central storage location

t_s = normal walking speed in man-minutes per foot while pushing a cart on hospital floors

t_v = normal time in man-minutes for elevator travel per floor

t_w = normal time in man-minutes spent waiting for an elevator

W_c = average effective capacity of a cart in pounds

W_e = power consumed by an elevator in Kilowatts per hour

W_i = average amount of waste in pounds to be collected from the ith floor per day

y = useful life of carts and containers in years

Section 4.2.2 Gravity Chute - Manual System

A = total area of all floors in square feet

a_1 = area of building space, in square feet, allocated for housing containers and carts

$(\frac{a}{p})^I_y$, $(\frac{a}{p})^I_z$ = capital recovery factors

C = average wage rate per hour including overhead

C_c = total cost of traveling from an intermediate accumulation point to a gravity chute intake section, providing intake sections, and cleaning the chutes

C_1 = cost per container

C_2 = cost per cart

C_3 = annual rental cost per square foot of building space

C_4 = cost of one waste container liner

C_6 = cost of an intake section, including building preparation work and installation

C_7 = cost of a discharge door arrangement at the bottom of a chute including installation

Cg = equipment cost of the chutes in a gravity chute system

d_a = average distance in feet from the bottom of the chutes to the central storage location

Eg_1 = annual equivalent cost of a gravity chute-manual system

Eg_2 = total annual operating and maintenance cost of a gravity chute-manual system

Eg_3 = annual labor cost of a gravity chute-manual system

Eg_4 = annual cost of waste container liners used in a gravity chute-manual system

I = interest rate per year on the capital

i = index of a gravity chute; $i = 1, 2, \ldots, M$

M = number of gravity chutes

m_i = number of intake sections in the ith gravity chute

N_{opt} = optimal value of n

N_1 = number of containers in a gravity chute-manual system

N_2 = number of carts in a gravity chute-manual system

n = total number of intake sections

T = standard time in hours per day

T_C = cleaning time for chutes in minutes per day

T_H = horizontal travel time in minutes per day

T_L = loading time of chutes in minutes per day

T_N = normal time in minutes per day

T_U = unloading time of carts in minutes per day

t = normal time in man-minutes for taking one bag from the intermediate accumulation point and putting it into a chute (does not include travel time)

t_p = normal walking speed in man-minutes per foot while carrying a load

t_r = normal time in man-minutes for removing one bag from the cart and placing it in a container at the central storage location

t_s = normal walking speed in man-minutes per foot while pushing a cart

W = total amount of waste in pounds

W_c = average amount of waste, in pounds, transported per trip from the bottom of the chutes to the central storage location

w = average amount of waste, in pounds, carried per trip from intermediate accumulation points to the gravity chutes

y = useful life of carts and containers in years

z = useful life of a gravity chute in years

Section 4.2.3 Gravity Chute - Pneumatic System

A = total area of all floors in square feet

a_1 = area of building space, in square feet, for housing containers, chutes and discharge valves

a_2 = area of building space, in square feet, for housing blower and collection equipment

$(\frac{a}{p})^I_y$, $(\frac{a}{p})^I_z$, $(\frac{a}{p})^I_x$ = capital recovery factors

C = average wage rate per hour including overhead

C_1 = cost per container

C_{3_1} = annual rental cost per square foot of space for housing containers, chutes and discharge valves

C_{3_2} = annual rental cost per square foot of space for housing blower and collection equipment

C_4 = cost of one waste container liner

C_5 = electricity cost per kilowatt hour

C_6 = cost per intake section including building preparation work and installation

C_7 = cost per discharge valve

C_8 = cost per foot of a pneumatic tube including installation, welding, and allowance for fittings and air inlets

C_9 = cost of a blower, as a function of L

C_{10} = cost of a control system, as a function of M and L

C_{11} = cost of auxiliary equipment such as sound attenuators, collection hoppers, filters, control panels, etc.

Cp = cost of pneumatic tube equipment

Cq = cost of gravity chute equipment

Et_1 = annual equivalent capital cost of a gravity chute-pneumatic tube system

Et_3 = annual labor cost of a gravity chute-pneumatic tube system

Et_4 = annual cost of liners used in a gravity chute-pneumatic tube system

Et_5 = annual electricity cost of a gravity chute-pneumatic tube system

I = interest rate per year on the capital

i = index of gravity chutes; $i = 1, 2, \ldots, M$

K = rated horse power of blower

L = total length of the pneumatic tube

M = number of gravity chutes

m_i = number of intake sections in the ith gravity chute

N_{opt} = optimal value of n

N_1 = number of containers in a gravity chute-pneumatic tube system

n = total number of gravity chute intake sections

P_p = total electricity consumption in kilowatt hour per day

S = speed in feet per second at which waste travels through a pneumatic tube

T = standard time in hours per day

T_C = cleaning time for chutes in minutes per day

T_H = horizontal travel time in minutes per day

T_L = loading time in minutes per day

T_N = normal time in minutes per day

t = normal time in man-minutes required for taking one bag from an intermediate accumulation point and putting it into a chute (does not include travel time)

t_p = normal walking speed in man-minutes per foot while carrying a load

W = total amount of waste in pounds

w = average amount of waste in pounds carried per trip from intermediate accumulation points to a gravity chute

x = useful life of pneumatic tube equipment in years

y = useful life of containers and carts in years

z = useful life of gravity chutes in years

α = time in seconds to open and close a discharge valve

β = average weight in pounds discharged each time a valve opens

Section 4.2.4 Pneumatic Tube System

L = total length of the pneumatic tube

S = speed in feet per second at which waste travels through a pneumatic tube

V = average height of the vertical chutes

W = total amount of waste in pounds

w = average amount of waste in pounds carried per trip from an intermediate accumulation point to a pneumatic tube intake section

Section 4.3.1 Incineration

a_1 = area in square feet for housing an incinerator

$(\frac{a}{p})^I_x$ = capital recovery factor

C = average wage rate per hour including overhead

C_1 = capital cost of an incinerator

C_2 = utility cost per pound per hour

C_3 = rental cost per year per square foot of space for housing an incinerator

Eb_1 = annual equivalent capital cost of an incineration system

Eb_2 = total annual operating cost of an incineration system

Eb_3 = annual labor cost of an incineration system

Eb_4 = annual utility cost of an incineration system

Eb_5 = maintenance and repair costs per year of an incineration system

I = interest rate per year on the capital

Q = burning capacity in pounds per hour

Q' = effective burning capacity of an incinerator

W = amount of waste to be incinerated per day

x = useful life of incinerator in years

α = incinerator efficiency factor

Section 4.3.2 Compaction

a_{1_1} = area of building space in square feet required for the installation of a compaction system

a_{1_2} = area of building space in square feet required for the operation of a compaction system

$(\frac{a}{p})^I_y$ = capital recovery factor

C = average wage rate per hour including overhead

C_1 = cost of a compactor container

C_2 = cost of a compactor

C_{3_1} = annual rental cost of building space for housing a compaction system

C_{3_2} = annual rental cost of building space for operating a compaction system

C_4 = hauling cost per trip

C_5 = electricity cost per kilowatt hour
Ec_1 = annual equivalent capital cost of a compaction system
Ec_2 = annual operating cost of a compaction system
Ec_3 = annual hauling cost of a compaction system
Ec_4 = annual labor cost of a compaction system
Ec_5 = annual electricity cost of a compaction system
Ec_6 = annual germicidal cost of a compaction system
I = interest rate per year on the capital
K = rated horse power of the compactor motor
r = capacity of a compactor container in cubic yards
t_m = cycle time of a compactor in seconds
W = average amount of waste to be hauled in pounds per day
W_c = average effective capacity of a cart in pounds
y = useful life of compaction equipment in years

Section 4.3.3 Pulping

a_1 = area of building space in square feet required for the installation of a pulping system
a_2 = area of building space in square feet required for the operation of a pulping system
$(\frac{a}{p})^I_y$ = capital recovery factor
C = average wage rate per hour for the non-engineering staff
C_g = water cost per gallon
C_1 = cost of a suitable size pulper
C_2 = cost of an extractor
C_{3_1} = annual rental cost of building space for housing a pulping system
C_{3_2} = annual rental cost of building space for operating a

pulping system

C_4 = hauling cost for a container of r cubic yard capacity

C_5 = electricity cost per kilowatt hour

C' = average wage rate per hour for the engineering staff

C'_1 = cost of a container in which pulped waste is deposited

C'_2 = cost of automatic feeding arrangement

C'_3 = cost per foot of pipe

Ep_1 = annual equivalent capital cost of a pulping system

Ep_2 = total operating and maintenance cost per year of a pulping system

Ep_3 = annual labor cost of a pulping system

Ep_4 = electricity cost per year of a pulping system

Ep_5 = annual cost of the sanitizer used in a pulping system

Ep_6 = annual cost of water used in a pulping system

Ep_7 = annual cost of replacement parts for a pulping system

Ep_8 = annual hauling cost of a pulping system

g = amount of water consumed in gallons per day

H_k = combined rated horsepower of all motors

h = number of hours the pulping system is in actual operation per day

I = interest rate per year on the capital

L = length of the pipe

r = capacity of the container to hold the pulp in cubic yards

T_1 = man-hours spent per year on the pulping system by the engineering staff

T_2 = man-hours spent per year on the pulping system by the non-engineering staff

W = amount of waste to be pulped in pounds per day

y = useful life of the pulping equipment in years

CHAPTER VI. STUDY OF SCOPE OF CENTRALIZATION

Section 6.1 Introduction

A_1, A_2, A_3 = constants

C_1 = land and building structure cost

C_2 = incinerator equipment cost

C_3 = operating cost

Z = centralized incinerator plant capacity

Section 6.2.1 Formulation 1

a_j = treatment cost per ton at plant j

C_{ij} = annual variable cost of disposing of waste from hospital i through plant j

d_{ij} = distance of hospital i from plant j in miles

d_j = distance of plant j from the nearest available landfill in miles

F_j = fixed cost associated with plant j

i = index for hospital; $i=1, 2, \ldots, n$

j = index for incinerator plants; $j=1, 2, \ldots, m$

m = number of potential incinerator plants

n = number of hospitals considered for centralization

P = fraction of waste left after incineration

Q_i = amount of waste in tons per year to be treated from hospital i

t_{ij} = transportation cost per ton from hospital i to plant j

t_j = transportation cost per ton from plant j to the landfill

u = variable cost per ton per mile for transporting waste

V_j = fixed plant capacity of plant j in tons per year (assumed to be given)

v = fixed cost per ton for a waste pickup at a hospital

v' = fixed cost per ton for a pickup at an incineration plant

$Y_j = \begin{cases} 1, \text{ if plant j is built} \\ 0, \text{ otherwise} \end{cases}$

$X_{ij} = \begin{cases} 1, \text{ if waste from hospital i disposed of through plant j} \\ 0, \text{ otherwise} \end{cases}$

Section 6.2.2 Formulation 2

a_{jk} = treatment cost per ton at plant j over capacity range V_{k-1} to V_k

d_{ij} = distance of hospital i from plant j in miles

d_j = distance of plant j from the nearest available landfill in miles

F_{jk} = fixed cost of plant j over capacity range V_{k-1} to V_k

i = index for hospitals; $i=1, 2, \ldots, n$

j = index for incinerator plants; $j=1, 2, \ldots, m$

k = index of capacity range V_{k-1} to V_k; $k=1, 2, \ldots, p$

m = number of potential incinerator plants

n = number of hospitals considered for centralization

P = fraction of waste left after incineration

p = number of ranges

Q_i = amount of waste in tons per year to be treated from hospital i

t_{ij} = transportation cost per ton from hospital i to plant j

t_j = transportation cost per ton from plant j to the landfill

V = plant capacity in tons per year

V_0 to V_1, V_1 to V_2,..., V_{p-1} to V_p = p ranges of capacity V

$$X_{ij} = \begin{cases} 1, \text{ if waste from hospital i disposed of through plant j} \\ 0, \text{ otherwise} \end{cases}$$

$$Y_{jk} = \begin{cases} 1, \text{ if plant j built and operated at a capacity range } V_{k-1} \text{ to } V_k \\ 0, \text{ otherwise} \end{cases}$$

APPENDIX A

CLASSIFICATION SCHEMES FOR HOSPITAL SOLID WASTE, AS SUMMARIZED FROM VARIOUS SOURCES*

Author	Year Presented	Classes of Hospital Solid Waste
American Public Health Association	1956	Garbage, rubbish (e.g. combustible and noncombustible solid waste), ashes, biological waste ("resulting directly from patient care activities, [and which] includes materials of medical, surgical, autopsy, and laboratory origin").
Deming	1958	Ordinary floor waste (e.g., paper), kitchen waste, pathological waste, X-ray and cast room waste, receiving room waste (e.g., large cartons), metal and glass.
McKenna	1963	Garbage, rubbish, ashes, pathological waste, critical waste (e.g., radioactive), and pathogen-contaminated waste.
Falick	1965	Garbage, rubbish, organic waste ("animal carcasses, organs, solid organic waste, and pathological waste"), other waste (rubber, plastics, metals, glass, etc.), and special waste ("radioactive and other waste representing a high degree of danger if handled and, [which] therefore, must be disposed of by separate means, by law").
Black	1967	Garbage, "paper, trash, and other dry combustibles", treatment room waste, surgery waste, autopsy waste, and noncombustibles.
Groce	1968	Garbage, rubbish, pathological waste (including body tissues, fluids, and bones), and infectious waste.

Author	Year Presented	Classes of Hospital Solid Waste
Holbrook	1968	Garbage and similar material capable of being ground for discharge to a sewerage system, "wet waste incompatible with the sewer and difficult to burn", combustible waste, "Pathological and radioactive wastes, which require special treatment because of contamination and which are usually regulated by statute", and noncombustible waste.

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*Reprinted from publication: Iglar, Albert F. and Bond, Richard G. Final Report Hospital Solid Waste Disposal in Community Facilities, School of Public Health, University of Minnesota, 1971.

APPENDIX B

CONTRIBUTIONS OF HOSPITAL SOLID WASTE PER PATIENT PRESENTED IN VARIOUS REFERENCES**

<table>
<tr><th>Source</th><th>Year Presented</th><th>Contribution of Solid Waste</th></tr>
<tr><td>Overton</td><td>1937</td><td>7 lb/day/bed*, comprising 40 percent to 50 percent garbage, and the balance rubbish.</td></tr>
<tr><td>Olson</td><td>1949</td><td>7.5 lb/day/bed*, compared with "government estimates" of 8 to 8.5 lb/day/bed*. The latter included 4 lb/day/bed* of "kitchen garbage".</td></tr>
<tr><td>American Hospital Assoc. Manual of Hospital Housekeeping</td><td>1952</td><td>7 lb/day/patient, average generation.</td></tr>
<tr><td>Incinerator Institute of America, "Bulletin H"</td><td>1955</td><td>Design basis for incinerators of 8 lb/day/bed*, plus 3 lb/day for each person in an "auxiliary section" (e.g., nurse's residence), plus 1 lb/patient in outpatient department. If garbage were excluded the first value might be reduced to 5 lb/day/bed*. Base incinerator design on 7 hr/day.</td></tr>
<tr><td>American Public Health Association</td><td>1956</td><td><table>
<tr><th>Mean Contributions:</th><th>lb/day/ patient</th><th>cu ft/day/ patient</th></tr>
<tr><td>Garbage</td><td>3.28</td><td>0.064</td></tr>
<tr><td>Noncombustibles</td><td>1.10</td><td>0.111</td></tr>
<tr><td>Combustibles</td><td>2.61</td><td>0.521</td></tr>
<tr><td>Surgical and autopsy waste</td><td>0.14</td><td>omitted</td></tr>
<tr><td></td><td>7.13</td><td>0.696</td></tr>
</table></td></tr>
<tr><td>Sister M. Clarisse</td><td>1958</td><td>7 lb/day/patient, for general hospitals.</td></tr>
<tr><td>Vance</td><td>1961</td><td>7 lb/day/patient, or almost 1 cu ft/day/patient.</td></tr>
<tr><td>Institutions Magazine</td><td>1961</td><td>7 to 8 lb/day/bed*.</td></tr>
<tr><td>Minerath (France)</td><td>1962</td><td>0.4 liter/day/bed*, apparently for wards only.</td></tr>
</table>

Source	Year Presented	Contribution of Solid Waste
Briosi (Italy)	1963	2 to 3 liters/day/patient.
Heyer (Germany)	1963	1 liter/day/patient.
McKenna	1963	9.6 lb/day/bed*, or 1.7 cu ft/day/bed* for a 1,000 bed military hospital.
Paul	1964	Estimates of combustible waste generation has risen from 8 lb/day/patient "a few years ago", to 10 lb/day/patient, or more.
Farr and Healy (discussing British Standards)	1965	Recommended values, in absence of specific data, were 5 lb/day/bed*, or 0.5 cu ft/day/bed*. A range was reported of 0.1 to 0.93 cu ft/day/bed*.
Falick	1965	Estimated increase from approximately 6 lb/day/patient in 1955 to 13 lb/day/patient in 1975.
Holbrook	1966	19 lb/day/patient at a teaching hospital with 1,100 beds. (Included 8.3 lb/day/patient of garbage and noncombustibles, and 10.7 lb/day/patient of "readily burnable material".)
Incinerator Institute of America, Incinerator Standards	1966	Design basis for incinerators of 8 lb/day/bed*, and 6 hr/day of operation.
Rourke	1967	Estimated increase during preceding 10 years from 6 to 9 lb/day/patient, to 20 lb/day/patient.
Oviatt	1967	4.3 to 11.0 lb/day/patient found at hospitals with 200 to 725 beds.
Holbrook	1967	20 lb/day/patient.
Syska and Hennessy, Inc., Engineers	1968	17 lb/day/patient.

Source	Year Presented	Contribution of Solid Waste
Davis	1968	Estimated 12 lb/day/bed*.
Baker	1968	Mean of 12.3 lb/day/bed* found at 7 hospitals (range of 9 to 19 lb/day/bed*).
Groce	1968	Estimated increase in preceding 10 years from 6 to 9 lb/day/patient, to 12 to 19 lb/day/patient.
Jacobsen	1969	15 lb/day/bed*.
Syska and Hennessy, Inc., Engineers	1969	At least 10 lb/day/bed* from "general hospital buildings, excluding food service wastes and loads from auxiliary buildings". Waste contribution was expected to peak at 20 to 25 lb/day/bed*.
Plate, Cup, and Container Institute, Inc.	Undated. Received 1969.	Estimate of 30 lb/day/patient for one hospital, "consistent with national averages".

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[*] Contribution of solid waste listed as "lb/day/bed" may be converted to "lb/day/patient" by using percent occupancy of the hospital, as follows: lb/day/patient = (100 percent occupancy)(lb/day/bed). Since nongovernmental, nonprofit hospitals have an average occupancy of 80 percent, the conversion factor would typically be 1.25.

[**] Reprinted from publication: Iglar, Albert F. and Bond, Richard G. Final Report Hospital Solid Waste Disposal in Community Facilities, School of Public Health, University of Minnesota, 1971.

APPENDIX C

SUMMARY OF DISPOSABLES QUESTIONNAIRE

Data collected during the period 1967 to 1969 as part of the study "Hospital Solid Waste Disposal in Community Facilities" by Iglar and Bond[18] form the basis for the regression analysis performed in Chapter III to estimate the quantity of solid waste generated from a given hospital. Data pertaining to several hospital parameters which could affect waste generation were not obtained at the time of the original surveys in 1967-1969. In order to include these parameters in the regression analysis, questionnaires were sent to the 86 general hospitals surveyed by Iglar and Bond.

Several questions were asked relating to the average number of meals served per day, the number of nurses in the training school, and whether there was a computer data center in the hospital at the time of the original survey.

The extent of usage of single-use items in hospitals and their corresponding effect on the quantity of solid waste generated in the hospital vary considerably. The questionnaire was designed to obtain information on the use of single-use items at the time of the original survey and in 1971-1972. From the literature and visits to hospitals, a list of single-use items was developed. Certain single-use items, such as paper towels used in the washroom, plastic or paper waste receptacle liners and single-use needles and syringes, which are commonly used in hospitals were not included in the list. The list was developed to include single-use items which have reusable substitutes that are still used in many hospitals. A further constraint on the items included in the list was that they would contribute significantly to the weight of solid waste generated in the hospital. A copy of the questionnaire is given in Table C.1, and a tabulation of responses is given in Table C.2. A total of 25 types of single-use items were listed:

Six patient care items: linen, diapers, bed pans, wash basins, emesis basins and patient care kits.
Seven surgical items: drapes, face masks, surgeon's caps, nurse's caps, shoe covers, gloves, gowns.
Three dietary items: cutlery, dishes, trays.
Nine laboratory, x-ray and emergency room items: slides, test tubes, pipettes, petri dishes and culture tubes, urine and stool specimen cups, sputum containers, lab gowns, x-ray or exam gowns, and stretcher or exam table covers.

In the case of single-use dietary items, the hospitals were asked to indicate if the items were used for isolation patients, all patients, employees, and/or visitors. The extent of usage of the other items was not asked, although several hospitals did volunteer this information. However, from observations of typical hospitals, general assumptions on the extent of usage of certain items were made.

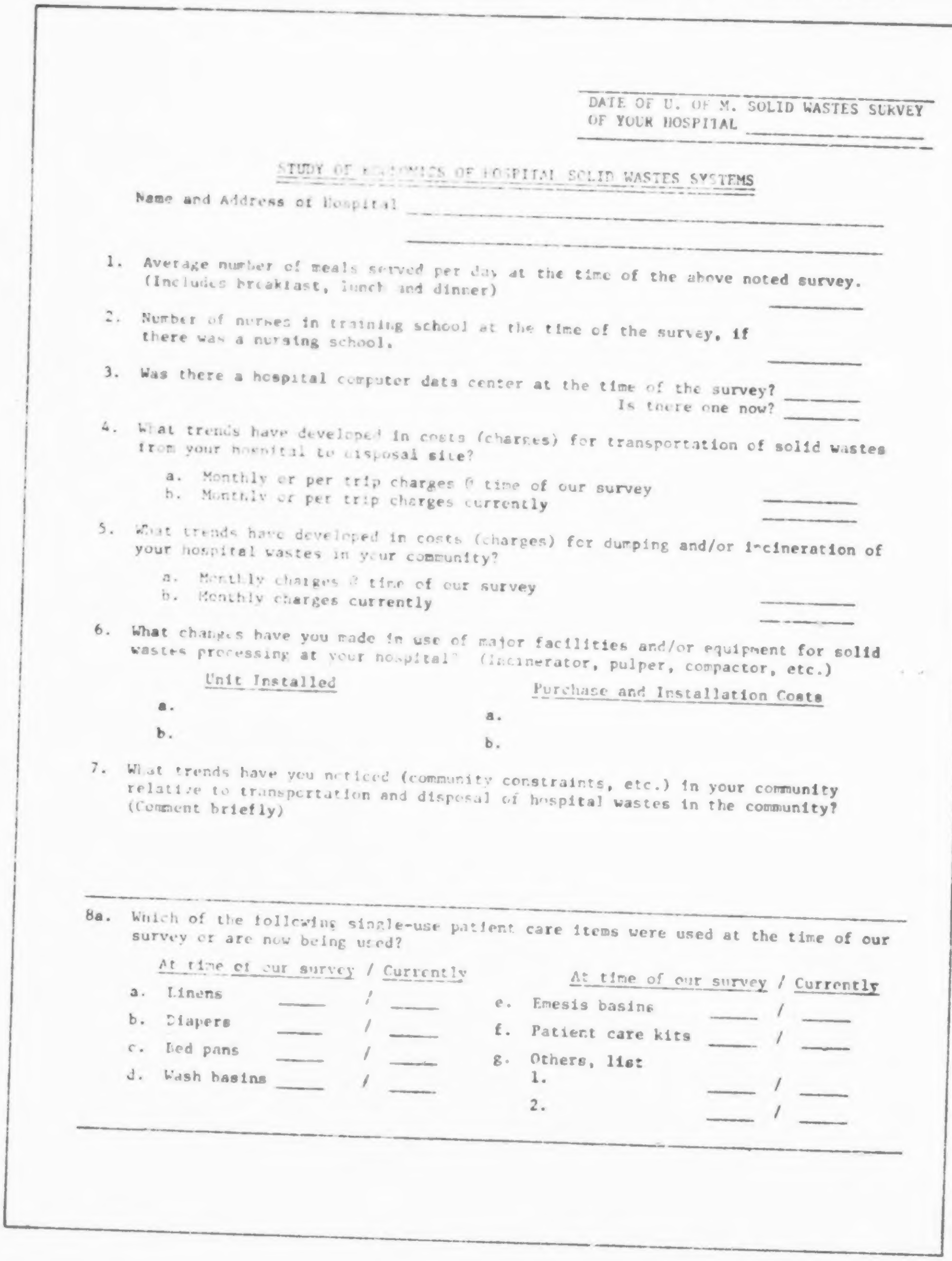
Fifty-five of the 86 hospitals contacted responded to the questionnaire. Forty-seven hospitals of those responding provided sufficient information to be included in the regression analysis.

In 1967-1969, the 47 hospitals were using an average of 13 single-use items. These items included two patient care items, four surgical items, two dietary items and five lab, x-ray and emergency room items. In 1971-1972 the hospitals were using an average of 15 items with the addition of one patient care item and one surgical item.

Every single-use item of the 25 listed above was used in more hospitals in 1971-1972 than it was at the time of the original surveys.

TABLE C.1

QUESTIONNAIRE SENT TO 86 GENERAL HOSPITALS SURVEYED IN 1967 - 1969 TO OBTAIN INFORMATION CONCERNING THE USE OF DISPOSABLES AND OTHER FACTORS AFFECTING THE COSTS OF HANDLING HOSPITAL SOLID WASTE



DATE OF U. OF M. SOLID WASTES SURVEY
OF YOUR HOSPITAL ____________

STUDY OF ECONOMICS OF HOSPITAL SOLID WASTES SYSTEMS

Name and Address of Hospital ______________________________
____

1. Average number of meals served per day at the time of the above noted survey. (Includes breakfast, lunch and dinner) ________

2. Number of nurses in training school at the time of the survey, if there was a nursing school. ________

3. Was there a hospital computer data center at the time of the survey? ________
Is there one now? ________

4. What trends have developed in costs (charges) for transportation of solid wastes from your hospital to disposal site?
   a. Monthly or per trip charges @ time of our survey ________
   b. Monthly or per trip charges currently ________

5. What trends have developed in costs (charges) for dumping and/or incineration of your hospital wastes in your community?
   a. Monthly charges @ time of our survey ________
   b. Monthly charges currently ________

6. What changes have you made in use of major facilities and/or equipment for solid wastes processing at your hospital? (Incinerator, pulper, compactor, etc.)

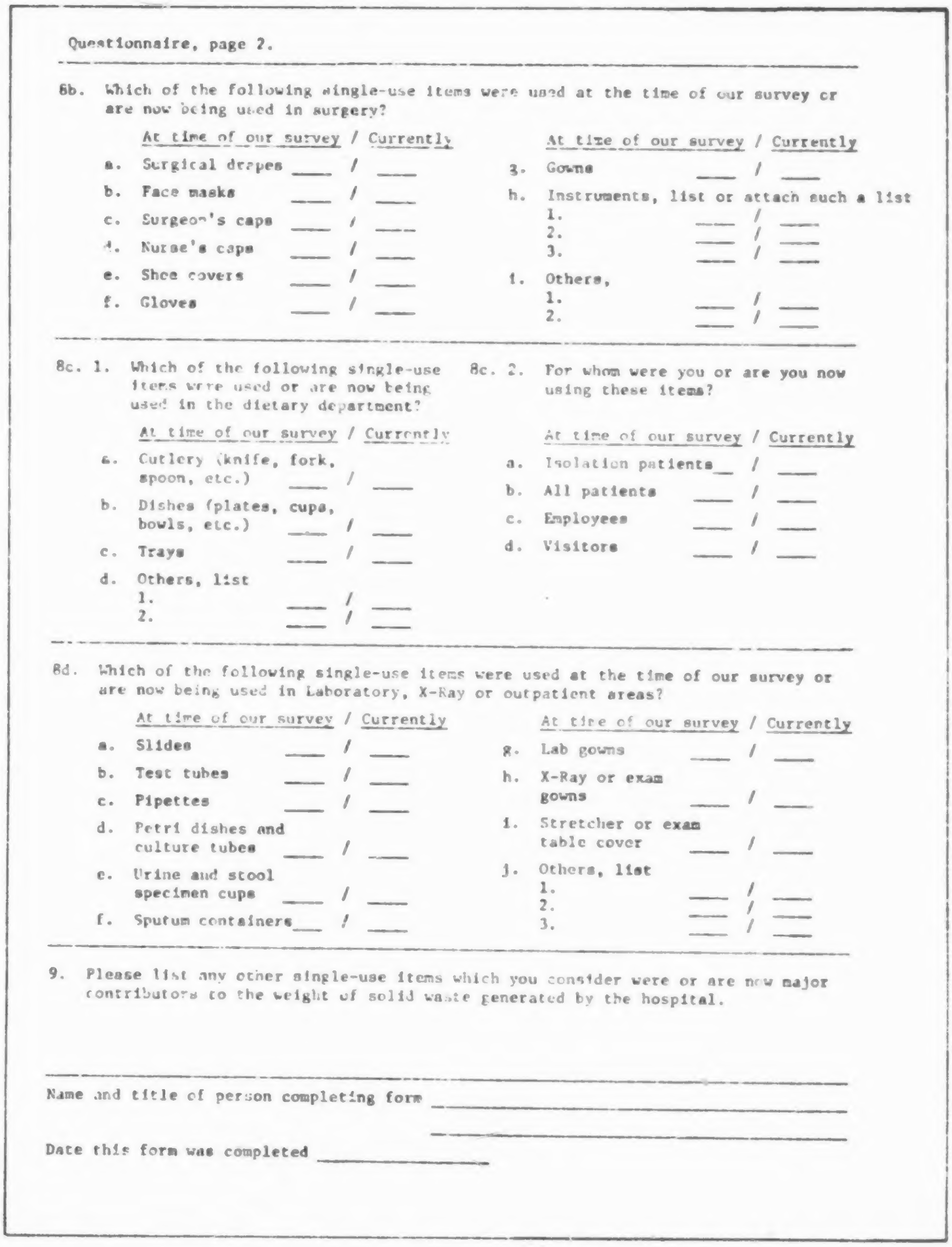
Unit Installed	Purchase and Installation Costs
a.	a.
b.	b.

7. What trends have you noticed (community constraints, etc.) in your community relative to transportation and disposal of hospital wastes in the community? (Comment briefly)

8a. Which of the following single-use patient care items were used at the time of our survey or are now being used?

	At time of our survey / Currently		At time of our survey / Currently
a. Linens	____ / ____	e. Emesis basins	____ / ____
b. Diapers	____ / ____	f. Patient care kits	____ / ____
c. Bed pans	____ / ____	g. Others, list	
d. Wash basins	____ / ____	1.	____ / ____
		2.	____ / ____

TABLE C.1 (continued



Questionnaire, page 2.

8b. Which of the following single-use items were used at the time of our survey or are now being used in surgery?

At time of our survey / Currently

a. Surgical drapes ____ / ____
b. Face masks ____ / ____
c. Surgeon's caps ____ / ____
d. Nurse's caps ____ / ____
e. Shoe covers ____ / ____
f. Gloves ____ / ____

At time of our survey / Currently

g. Gowns ____ / ____
h. Instruments, list or attach such a list
1. ____ / ____
2. ____ / ____
3. ____ / ____
i. Others,
1. ____ / ____
2. ____ / ____

8c. 1. Which of the following single-use items were used or are now being used in the dietary department?

At time of our survey / Currently

a. Cutlery (knife, fork, spoon, etc.) ____ / ____
b. Dishes (plates, cups, bowls, etc.) ____ / ____
c. Trays ____ / ____
d. Others, list
1. ____ / ____
2. ____ / ____

8c. 2. For whom were you or are you now using these items?

At time of our survey / Currently

a. Isolation patients__ / ____
b. All patients ____ / ____
c. Employees ____ / ____
d. Visitors ____ / ____

8d. Which of the following single-use items were used at the time of our survey or are now being used in Laboratory, X-Ray or outpatient areas?

At time of our survey / Currently

a. Slides ____ / ____
b. Test tubes ____ / ____
c. Pipettes ____ / ____
d. Petri dishes and culture tubes ____ / ____
e. Urine and stool specimen cups ____ / ____
f. Sputum containers___ / ____

At time of our survey / Currently

g. Lab gowns ____ / ____
h. X-Ray or exam gowns ____ / ____
i. Stretcher or exam table cover ____ / ____
j. Others, list
1. ____ / ____
2. ____ / ____
3. ____ / ____

9. Please list any other single-use items which you consider were or are now major contributors to the weight of solid waste generated by the hospital.

Name and title of person completing form ______________________________

Date this form was completed ______________

TABLE C.2

SUMMARY OF RESPONSES OF 47 HOSPITALS TO DISPOSABLES QUESTIONNAIRE

	Patient care items						Surgical items							Dietary items							Laboratory, x-ray & emergency items									
Hospital	Linen	Diapers	Bed pans	Wash basins	Emesis basins	Patient care kits	Drapes	Face masks	Surgeon's caps	Nurse's caps	Shoe covers	Gloves	Gowns	Cutlery	Dishes	Trays	Isolation patients	All patients	Employees	Visitors	Slides	Test tubes	Pipettes	Petri dishes & culture tubes	Urine & stool specimen cups	Sputum containers	Lab gowns	X-ray or exam gowns	Stretcher or exam table cover	Computer center
1	X	OX			X	OX	OX	OX	X	OX	OX	OX	X	OX	OX	X	OX				OX	OX	OX	O	OX	OX			X	
2	OX	OX	X	X	X	X	OX	OX	OX	OX	OX	OX	X	OX	OX		OX		partially		OX	OX	OX	OX	OX	OX			OX	OX
3							OX	OX	OX	OX	OX	OX		OX	OX		OX		partially		OX			OX	OX	OX				OX
4		X			X	X	X	X	X	X	X	OX		OX	OX	OX	OX				OX	OX	OX	OX	OX	XO				X
5		X				OX		X		X	X	X		OX	OX	OX	OX				OX	OX	OX	OX	OX	OX				
6		OX	O		OX	O		OX		OX		OX			OX			OX	OX	OX	OX	OX	OX		OX	OX			OX	
7		X				OX		X		X	X	OX		OX	OX		OX	X							X	OX				
8		OX		X	X	X		OX	X	X	X	X		OX	OX	OX	OX				OX	OX	OX	OX	X	X				X
9	OX		OX	OX	OX	OX	OX	OX	OX	OX	OX	OX		OX	OX	OX	OX				OX	OX	OX	OX	OX	OX	OX	OX	OX	
10		OX				OX	OX	OX	OX	OX	OX	OX	OX												OX				X	
11							X	X				X		OX			OX							X						X
12		OX				OX		OX		OX	X	X	OX	OX	OX		OX				OX	OX	OX	OX	OX	OX				
13								X		OX		OX		X	OX	X	OX				OX	OX	OX	OX	OX	OX	X		X	X
14						OX	X	X	X	X	OX	X	OX								OX	OX	OX	OX	OX	OX				
15	OX	OX		OX		OX	OX	OX	OX	X	OX	OX	X	OX	OX	OX	OX		X	X	X	X	X	OX	OX	OX				
16							X	OX		X	OX				X	X	X								OX	OX	X		OX	
17		X				X		OX		OX	X	OX		OX	OX	OX	OX				OX	OX	OX	OX	OX	OX			OX	X
18		O	X	X	X	OX		OX				OX		OX	OX	OX	OX							OX	OX	OX				OX
19		X					OX	OX	OX	OX		OX		OX	OX		OX					OX	X	OX	OX	OX			X	
20					OX	OX				OX															OX	OX			OX	
21				X	X	OX	X	OX	X	X	X	OX	X	OX	OX	OX	OX				OX	X	OX	OX	OX	OX				
22				OX	OX	OX		OX	OX	OX	OX	OX		OX	OX	OX	OX				OX	OX	OX	OX	OX	OX	OX			X
23			X	X	X	X	X	X	X	X	X	X		OX	OX	OX	OX				X	X	X	X	X	X				OX
24		OX				OX	X	OX	X	OX		X		OX	X		OX				OX	OX		OX	OX	OX				
25							X	OX	X	OX		OX	X	OX	OX	OX	OX		Cutlery		OX	OX	OX	OX	OX	OX				OX
26					OX	OX		OX		OX	OX	OX									OX	OX		OX	X	OX				
27	OX	OX			OX	OX	OX	OX		OX	OX	OX	OX	OX	OX		OX				OX	OX		OX	OX	OX			X	
28		OX				X	X	OX		OX	OX	OX		OX	OX		OX				OX	OX	OX	OX	OX	OX				X
29		OX				X		OX		X		OX		OX	OX	OX	OX							OX	OX	OX				
30	X	O	OX	OX	OX	OX	OX	OX	OX	OX	OX	OX	X	OX	OX	OX	OX				OX	OX	OX	OX	OX	OX	OX	OX	OX	
31	X	X		OX	OX	OX	X	OX	OX	OX	OX	OX	X	OX	OX	OX	OX				OX	OX	OX	OX	OX	OX				
32		OX				OX		OX	OX		OX	OX			OX		OX							OX	OX	OX				
33			OX	OX	OX	OX	OX	OX		OX	OX	OX	OX	OX	OX				OX	OX	OX	OX	OX	OX	OX	OX				OX
34	OX	O	OX	OX		O	OX	OX	OX	OX		OX	OX								OX			OX	OX	OX			OX	
35		OX			OX	OX	X	OX	OX	OX	OX	OX												OX	OX	OX				OX
36			OX	OX	OX	OX	OX	OX	OX	OX	OX	OX	OX	OX	OX		OX				OX	OX	OX	OX	OX	OX				
37		OX		OX	OX	OX		OX	OX	OX	OX	OX									OX	OX	OX	X	OX	OX				OX
38		OX			X	OX		X				OX		OX	OX	OX	OX				OX	X		X	OX	OX				
39		OX		X	X	OX	X	OX		OX	O	OX	X	OX	OX	OX	OX				OX	OX			OX	OX				OX
40	OX	OX	OX	OX	OX	OX	O	X	X	O		OX	OX								OX	OX		OX	OX	OX			X	
41		X	X		OX	OX	OX	OX	OX	X		OX									OX	OX	OX	OX	OX	OX				X
42		OX	OX	O	OX	OX		OX	OX	OX		OX		OX	OX		OX		OX		OX		OX	OX	OX	OX			OX	X
43							X					X	X	OX	OX		OX				OX	OX		OX	OX	OX				
44								OX		OX	OX	OX		OX	OX		OX		OX		O	O	O	O	X	O			O	OX
45		OX				OX		OX	OX	OX	OX	OX	OX		OX			OX	OX	OX		OX	OX	OX	OX	OX			X	
46		OX				OX	OX	OX	OX	OX	OX	OX	O								OX	OX		OX	OX	OX				X
47							OX	OX	X	OX	OX	OX		OX	OX	OX	OX	some			OX			OX	OX	OX			OX	OX

Legend: O: Items were used in 1967 - 1969
X: Items were used in 1971 - 1972

More hospitals increased their usage of items from the surgical category than from any of the other three categories.

Only five hospitals were using fewer single-use items in 1971-1972 than at the time of the original surveys, while 34 hospitals were using more items. The five hospitals were using an average of two fewer items, and the 34 hospitals were using an average of three more items.

Patient Care Items

At the time of the original survey, the 47 hospitals were using an average of two single-use patient care items. Generally the two items were diapers and patient care kits. In 1971-1972 the hospitals were using an average of three items with the addition of either a wash or emesis basin. Of the 17 hospitals which were using additional items, 11 hospitals added two or more items.

Twenty-seven hospitals were using the same single-use patient care items that they used at the time of the original survey. Of that number, eight hospitals were not using any of the items and eight hospitals were using four or more of the items.

Table C.3 shows a breakdown of the number of hospitals using the various single-use patient care items at the time of the original survey and in 1971-1972.

Single-use linen, which was used in seven hospitals at the time of the original survey and in 11 hospitals in 1971-1972, is generally used only in such areas as isolation or burn wards. Storage space requirements and the volume of solid waste that they generate are two reasons why hospitals do not use single-use linen for all patients.

TABLE C.3

BREAKDOWN OF THE NUMBER OF HOSPITALS USING CERTAIN SINGLE-USE PATIENT CARE ITEMS, AT THE TIME OF THE ORIGINAL SURVEY AND PRESENTLY

Single-use item	No. of hosps. using item			
	1967 - 1969		1971 - 1972	
Linen	YES	6	YES	6
			NO	0
	NO	41	YES	3
			NO	38
Diapers	YES	23	YES	20
			NO	3
	NO	24	YES	7
			No	17
Bed pans	YES	8	YES	7
			NO	1
	NO	39	YES	4
			NO	35
Wash basins	YES	12	YES	11
			NO	1
	NO	35	YES	6
			NO	29
Emesis basins	YES	15	YES	15
			NO	0
	NO	32	YES	9
			NO	23
Patient care kits	YES	32	YES	31
			NO	1
	NO	15	YES	9
			NO	6

Patient care kits were used in 32 hospitals at the time of the original survey, and in 39 hospitals in 1971-1972. The contents of the kits can vary considerably from kits with just a water carafe and a few cups to kits containing 16 or more items. The extent of use of the kits varies from use for all patients to use in only special areas such as OB, ICU and CCU.

Except for single-use diapers which have been discontinued in three of 23 hospitals, no other item has been discontinued in more than one hospital. Reasons why the three hospitals have discontinued using the single-use diaper might include their cost, reliability and storage space requirements.

Surgical Items

The 47 hospitals were using an average of four of the single-use surgical items at the time of the original survey. Generally the four items were face masks, gloves, nurse's caps and either shoe covers or surgeon's caps. In 1971-1972 the hospitals were using an average of five items with the addition of surgical drapes.

Twenty-seven hospitals were using more single-use surgical items in 1971-1972 than they did at the time of the original survey. Of that number, 17 hospitals added two or more of the items. Although four hospitals did not use any of the items at the time of the original survey, all of the hospitals were using at least one item in 1971-1972. At the time of the original survey, 16 hospitals used two or less of the items, and 21 hospitals used five or more items. In 1971-1972 only three hospitals were using two or less of the items, and 31 hospitals were using five or more items.

Nineteen hospitals were using the same single-use surgical items that they used in 1967-1969. Of that number, 16 hospitals were using four or more of the items.

Table C.4 shows a breakdown of the number of hospitals using the various single-use surgical items at the time of the original survey and in 1971-1972.

Single-use surgical drapes were used in 16 hospitals at the time of the original survey, and in 28 hospitals in 1971-1972. Five hospitals indicated that they were using the single-use surgical drapes for only a small percentage of the surgical procedures performed. Although the other hospitals did not indicate the extent of use, observations of hospitals suggest that the single-use surgical drapes are generally used for only certain surgical procedures. The drapes, specifically designed for a particular procedure, come as part of a surgical kit which often includes single-use surgical instruments.

Single-use face masks, nurse's caps and gloves, which were used in approximately 75% of the hospitals in 1967-1969, were being used in all but three of the hospitals in 1971-1972.

Laboratory, X-Ray and Emergency Room Items

The 47 hospitals were using an average of five items at the time of both surveys. Generally the five items are from a group which includes slides, test tubes, pipettes, petri dishes and culture tubes, specimen cups, and sputum containers.

Thirty hospitals were using the same single-use items that they used in 1967-1969. Of that number, 18 hospitals were using six or more of the items.

TABLE C.4

BREAKDOWN OF THE NUMBER OF HOSPITALS USING CERTAIN SINGLE-USE SURGICAL ITEMS, AT THE TIME OF THE ORIGINAL SURVEY AND PRESENTLY

Single-use item	No. of hosps. using item			
	1967 - 1969		1971 - 1972	
Drapes	YES	16	YES	15
			NO	1
	NO	31	YES	13[a]
			NO	18
Face masks	YES	36	YES	36
			NO	0
	NO	11	YES	9
			NO	2
Surgeon's caps	YES	18	YES	18
			NO	0
	NO	29	YES	10
			NO	19
Nurse's caps	YES	31	YES	30
			NO	1
	NO	16	YES	11
			NO	5
Shoe covers	YES	24	YES	23
			NO	1
	NO	23	YES	8
			NO	15
Gloves	YES	37	YES	37
			NO	0
	NO	10	YES	7
			NO	3
Gowns	YES	9	YES	8
			NO	1
	NO	38	YES	9[a]
			NO	29
Drapes, masks, caps, gloves, shoe covers & gowns	YES	5	YES	4
			NO	1[b]
	NO	42	YES	7
			NO	35
Drapes, masks, caps, gloves & shoe covers	YES	12	YES	12
			NO	0
	NO	35	YES	6
			NO	29
Masks, caps, shoe covers & gloves	YES	23	YES	22
			NO	1[c]
	NO	24	YES	8
			NO	16

[a] Five hospitals indicate that they use single-use items occasionally.

[b] Hospital no longer uses single-use gowns.

[c] Hospital no longer uses single-use shoe covers.

Sixteen hospitals were using more of the single-use items than they did previously. Of that number, only six hospitals added more than one item.

Table C.5 shows a breakdown of the number of hospitals using these single-use items at the time of the original survey and in 1971-1972.

Single-use lab, x-ray and exam gowns were being used in only a few hospitals at the time of both surveys. Stretcher or exam table covers, which were used in 11 hospitals at the time of the original survey, were being used in 19 hospitals in 1971-1972.

One hospital, which used six items in 1967-1969, indicated that they no longer used the items.

Dietary Items

The common situation in the 47 hospitals was the use of single-use cutlery and dishes for only isolation patients, both at the time of the original survey and in 1971-1972. Of the 29 hospitals that were using single-use cutlery and dishes for isolation patients, nearly two-thirds also were using single-use trays.

Thirty-eight hospitals were using the same single-use dietary items that they used in 1967-1969. Of that number, 34 hospitals were using the items for the same groups of people as they did previously.

If single-use dietary items were used for all patients, the items were also used for employees and visitors at the time of both surveys. See tables C.6, C.7, and C.8.

TABLE C.5

BREAKDOWN OF THE NUMBER OF HOSPITALS USING CERTAIN SINGLE-USE LABORATORY, X-RAY AND EMERGENCY ITEMS, AT THE TIME OF THE ORIGINAL SURVEY AND PRESENTLY

Single-use item	No. of hosps. using item			
	1967 - 1969		1971 - 1972	
Slides	YES	33	YES	32
			NO	1[a]
	NO	14	YES	2
			NO	12
Test tubes	YES	30	YES	29
			NO	1[a]
	NO	17	YES	4
			NO	13
Pipettes	YES	24	YES	23
			NO	1[a]
	NO	23	YES	3
			NO	20
Petri dish, culture tubes	YES	37	YES	35
			NO	2[a]
	NO	10	YES	4
			NO	6
Specimen cups	YES	41	YES	41
			NO	0
	NO	6	YES	5
			NO	1
Sputum containers	YES	43	YES	42
			NO	1[a]
	NO	4	YES	2
			NO	2
Lab gowns	YES	3	YES	3
			NO	0
	NO	44	YES	2
			NO	42
X-Ray or exam gowns	YES	2	YES	2
			NO	0
	NO	45	YES	0
			NO	45
Stretcher or exam table cover	YES	11	YES	10
			NO	1[a]
	NO	36	YES	8
			NO	28
Slides, pipettes, test tubes, petri dish, culture tubes, specimen cups, sputum containers	YES	16	YES	15
			NO	1[a]
	NO	31	YES	5
			NO	26

[a] One hospital indicated that they no longer use six of the items they used at the time of the original survey.

TABLE C.6

BREAKDOWN OF THE NUMBER OF HOSPITALS USING SINGLE-USE DIETARY ITEMS FOR ISOLATION CASES, ALL PATIENTS, EMPLOYEES AND VISITORS*

Persons using item	No. of hosps. using item			
	1967 - 1969		1971 - 1972	
Isolation patients	YES	35	YES	35
			NO	0
	NO	7	YES	3
			NO	4
All patients	YES	4	YES	4
			NO	0
	NO	38	YES	1
			NO	37
Employees	YES	7	YES	7
			NO	0
	NO	35	YES	2
			NO	33
Visitors	YES	5	YES	5
			NO	0
	NO	37	YES	2
			NO	35
All patients, visitors & employees	YES	5[a]	YES	5[a]
			NO	0
	NO	37	YES	3[a]
			NO	34
Visitors & employees	YES	5	YES	5
			NO	0
	NO	37	YES	2
			NO	35

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[*] Only 41 of the 47 hospitals responded to this section of the questionnaire.

[a] One hospital uses certain single-use items for isolation patients, visitors and employees.

TABLE C.7

BREAKDOWN OF THE NUMBER OF HOSPITALS USING CERTAIN SINGLE-USE DIETARY ITEMS FOR ISOLATION PATIENTS AND ALL PATIENTS*

	No. of hosps. using item for isolation patients			No. of hosps. using item for all patients	
Single-use item	1967 - 1969	1971 - 1972	Single-use item	1967 - 1969	1971 - 1972
Cutlery	YES 30	YES 30	Cutlery	YES 4[a]	YES 4[a]
		NO 0			NO 0
	NO 12	YES 1		NO 38	YES 1
		NO 11			NO 37
Dishes	YES 33	YES 33	Dishes	YES 5[a]	YES 5[a]
		NO 0			NO 0
	NO 9	YES 2		NO 37	YES 0
		NO 7			NO 37
Trays	YES 17	YES 17	Trays	YES 2[b]	YES 2[b]
		NO 0			NO 0
	NO 25	YES 3		NO 40	YES 1
		NO 22			NO 39
Cutlery & dishes	YES 29	YES 29	Cutlery & dishes	YES 3[a]	YES 3[a]
		NO 0			NO 0
	NO 13	YES 0		NO 39	YES 1
		NO 13			NO 38
Cutlery, dishes & trays	YES 17	YES 17	Cutlery, dishes & trays	YES 1[b]	YES 1[b]
		NO 0			NO 0
	NO 25	YES 2		NO 41	YES 0
		NO 23			NO 41

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* Only 41 of the 47 hospitals responded to this section of the questionnaire.

[a] Three hospitals indicate that they use single-use items occasionally.

[b] One hospital only uses single-use cutlery, dishes and trays when serving snacks.

TABLE C.8

BREAKDOWN OF THE NUMBER OF HOSPITALS USING CERTAIN SINGLE-USE DIETARY ITEMS FOR EMPLOYEES AND VISITORS*

Single-use item	No. of hosps. using item for employees		Single-use item	No. of hosps. using item for visitors	
	1967 - 1969	1971 - 1972		1967 - 1969	1971 - 1972
Cutlery	YES 8[a]	YES 8[a]	Cutlery	YES 5[a]	YES 5[a]
		NO 0			NO 0
	NO 34	YES 1		NO 37	YES 3
		NO 33			NO 34
Dishes	YES 7[a]	YES 7[a]	Dishes	YES 3[a]	YES 3[a]
		NO 0			NO 0
	NO 35	YES 3		NO 39	YES 5
		NO 32			NO 34
Trays	YES 2	YES 2	Trays	YES 1	YES 1
		NO 0			NO 0
	NO 40	YES 1		NO 41	YES 2
		NO 39			NO 39
Cutlery & dishes	YES 5[a]	YES 5[a]	Cutlery & dishes	YES 3[a]	YES 3[a]
		NO 0			NO 0
	NO 37	YES 2[b]		NO 39	YES 3[b]
		NO 35			NO 36

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[*] Only 41 of the 47 hospitals responded to this section of the questionnaire.

[a] Two hospitals indicate that they use single-use items occasionally.

[b] Two hospitals also use single-use trays.

Summary

Of the 25 single-use items listed in the questionnaire, the 47 hospitals were using an average of 13 items in 1967-1969. The 13 items included two patient care items, four surgical items, two dietary items and five lab, x-ray and emergency room items. In 1971-1972 they were using an average of 15 of the items with the addition of one patient care item and one surgical item.

Although the average number of single-use patient care items used increased by one, the majority of the hospitals were using the same patient care items that they used at the time of the original survey. The increase is due to the fact that 25% of the hospitals added two or more items since the time of the original survey.

Sixty-five percent of the hospitals were using the same single-use lab, x-ray and emergency items that they used in 1967-1969. Thirty-five percent of the hospitals were using more items, but only 10% added more than one item.

Eighty percent of the hospitals were using the same single-use dietary items that they used in 1967-1969. Most of these hospitals were using the items for the same groups of people as they did in 1967-1969.

Approximately 60% of the hospitals were using more single-use surgical items than they did in 1967-1969. Nearly 40% of the hospitals added two or more items since the time of the original survey.

Presence of Computer Data Center at the Hospital

At the time of the original survey, 11 hospitals had or shared a computer data center. In 1971-1972 21 hospitals were using such a facility.

Trends in Community Constraints Relative to the Treatment, Hauling, and Disposal of Hospital Solid Waste

Twenty-two hospitals responded to the question asking for an indication of the trends in community constraints that had developed relative to the transportation and disposal of hospital wastes in the community. The responses indicated a general trend toward stricter controls over all phases of waste handling from pretreatment at the hospital to final disposal.

Relative to the treatment of solid wastes at the hospital, the trend toward stricter air pollution codes had forced six hospitals to purchase, improve or shut down their incinerators. Several hospitals mentioned the trend toward the use of compactors to handle the growing volume of solid waste generated in a hospital.

Although two hospitals previously used their own vehicles to haul waste to the landfill, all the hospitals were using municipal or private haulers to transport the hospital wastes in 1971-1972. Also mentioned was the trend toward more organized methods of collection, involving regular routes, enclosed vehicles and restrictions on the types of waste the haulers will handle.

The major trend in the disposal of solid wastes, which was mentioned by seven hospitals, had been away from disposal in an open dump to disposal in a sanitary landfill. Several communities had restricted burning or shut down their municipal incinerators and disposed of all wastes in a landfill. Controls at the landfills had become stricter with, in some cases, restrictions on the types of waste that would be handled or with fees charged for dumping, sometimes based on the size of the load.

The trends in community constraints seemed to be reflected in the new solid waste handling equipment that some of the hospitals installed. (See Table C.9). Stricter air pollution codes probably had an effect on the decision of six hospitals to purchase new incinerators or improve their present units. Possibly only six hospitals purchased or improved their incinerators because the hospitals were looking to other methods of waste handling, instead of trying to satisfy the stringent air pollution codes. This seems to be evident from the fact that 15 hospitals purchased or leased equipment, such as compactors, pulpers, garbage disposals and can/bottle crushers, to reduce the volume of waste that is stored and eventually hauled from the hospital.

The constraints that developed relative to burning, hauling and disposal of hospital wastes from the 22 hospitals seemed to have an effect on the hauling costs these hospitals were paying. In comparing hauling costs per month for the 22 hospitals in 1971-1972 versus the costs when the hospitals were surveyed sometime between 1967 and 1969, there was an average increase of over 90%. In the hospitals that installed new equipment which reduces the volume of waste hauled, the average increase in hauling costs per month was 25%. The average increase in hauling costs per month for all hospitals that responded to the questionnaire was 47%.

TABLE C.9

SUMMARY OF SOLID WASTE HANDLING EQUIPMENT INSTALLED SINCE 1967 - 1969

Type of Equipment		Number of Hospitals Installing Equipment	Average Cost	Actual Costs Reported
Incinerator		4	$5,758	6,332; 3,942; 7,000
Compactor	(own)	6	$5,370	6,646; 5,536; 3,500; 7,000; 5,500; 5,500; 4,045
	(lease)	6	$264/month	495/mth; 150/mth; 147/mth
Pneumatic Tube		1	$200,000	
Pulper	(kitchen)	1	$7,000	
	(general waste)	1	$55,000 (for two pulpers)	
Can/Bottle Crusher		1	$1,018	
Six Garbage Disposals		1	$5,888	
Incinerator improvement		1	$3,000	
Gas Burner for Incinerator		1	$335	

APPENDIX D

REGRESSION PROCEDURE AND ANALYSIS

In Chapter III regression analysis was used to develop estimates (y) of the total amount of solid waste generated in pounds per day from hospitals as a function of important hospital parameters. The analysis applies to general hospitals only, and separate analyses were made for hospitals located in SMSA (Standard Metropolitan Statistical Area) and for hospitals not located in SMSA. The data collected by Iglar and Bond[18] (adjusted for the use of disposables and computer services, as described in Section 3.2.4) were used in these analyses.

Notation:

y = weight of solid waste in pounds per day
x_1 = total hospital census, including newborn
x_2 = number of surgical operations per year
x_3 = number of out-patient visits per year
x_4 = total number of hospital employees
x_5 = number of nurses in the training school
x_6 = number of meals served per day
N = number of hospitals

These analyses are based on the usual assumptions about the residual errors, i.e., that these are random, independent, and normally distributed with mean zero and constant variance σ^2. The stepwise regression method* was used to select the independent variables to be successively included in the regression equation, obtaining the final equation of only statistically significant variables. The following steps were followed:

Step 1. A simple correlation coefficient matrix for the variables $(y, x_1, x_2, \ldots, x_6)$ considered in the analysis was generated from the observed data on these variables. The independent variable having the greatest correlation coefficient with the dependent variable was chosen as the first variable to be included in the regression. The correlation coefficient of this variable was tested for its significance. If this variable was found significant, the analysis proceeded to step 2 and, if this variable was not found significant, the analysis terminated.

Step 2. To select the second most statistically significant independent variable, the remaining independent variables were added to the regression one at a time to find the incremental sum of squares attributable to regression because of the added variable. The variable which accounted

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*This method, instead of orthogonal regression technique, was used because of the availability of the program for this method. Moreover, the multicolinearity of the independent variables was not a serious problem in this case, since the multiple correlation coefficient (0.984) of the dependent variable with all the independent variables was greater than the largest simple correlation coefficient (0.929, between x_1 and x_4) between any two independent variables. This rule-of-thumb for testing the seriousness of multicolinearity of the independent variables is discussed by Donald E. Farrar, and Robert R. Glauber [11].

TABLE D.1

CORRELATION COEFFICIENT MATRIX FOR VARIABLES FOR HOSPITALS NOT IN SMSA

	y	x_1	x_2	x_3	x_4	x_5	x_6
y	1.00						
x_1	.965	1.00					
x_2	.895	.809	1.00				
x_3	.137	.090	.226	1.00			
x_4	.920	.929	.845	.045	1.00		
x_5	.361	.417	.271	.063	.582	1.00	
x_6	.429	.513	.251	.049	.554	.511	1.00

for the largest increment was tested for significance. If the variable was found significant, then step 2 was repeated. If it was insignificant, the analysis proceeded to step 3. This stage completes the selection of the independent variables to be included in the regression equations.

Step 3. The process terminated, and the regression equation between the dependent variable (y) and the significant independent variables was estimated.

For hospitals not in SMSA, the correlation coefficient matrix is shown in Table D.1. According to this table, the variable x_1 has the largest correlation coefficient with the dependent variable y, the value being 0.965. The critical value of the least squares correlation coefficient with 20 degrees of freedom (number of hospitals = N = 22) is 0.423 (found in tables of critical values at 0.95 degree of confidence). Therefore, since 0.965 is greater than 0.423, a significant linear relationship exists between y and x_1. The total sum of squares, denoted by SS, and regression sum of squares, denoted by SS_1, are given in Table D.2.

TABLE D.2

SUM OF SQUARES FOR REGRESSION OF y ON x_1

Regression Sum of Squares SS_1	Total Sum of Squares SS
5,307,790	5,704,590

The remaining independent variables were added in turn, and the regression sums of squares, denoted by SS_2, are given in Table D.3.

TABLE D.3

SUM OF SQUARES OBTAINED ON ADDING INDEPENDENT VARIABLES TO x_1

Added Variable	Sum of Squares Due to Joint Regression SS_2	Incremental Sum of Square Attributable to the added Variable SS_2-SS_1
x_2	5,525,360	217,570
x_3	5,321,930	14,140
x_4	5,332,070	24,280
x_5	5,341,930	34,140
x_6	5,319,230	11,440

The largest incremental sum of squares (SS_2-SS_1) attributed to an independent variable is 217,570, associated with the variable x_2. The largest sum of squares, denoted by SS_2', due to joint regression is 5,525,360. The error sum of squares is 179,230 ($SS-SS_2'$ = 5,704,590 - 5,525,360). A test using the F statistic is used to test the significance of x_2.

$$F \text{ (calculated)} = \frac{217{,}570 \times (20-1)}{179{,}230} = 22.5$$

$F_{.05;19,1}$ = 4.37 (from tables of F distributions at 0.95 degree of confidence with 19 and one degrees of the freedom in the numerator and denominator, respectively)

Since 22.5 is greater than 4.37, variable x_2 is significant. The independent variables x_3, x_4, x_5, and x_6 were added in turn to the variables x_1 and x_2, and the results obtained are shown in Table D.4.

TABLE D.4

SUM OF SQUARES OBTAINED ON ADDING INDEPENDENT VARIABLES TO x_1 AND x_2

Added Variable	Sum of Squares Due to Joint Regression SS_3	Incremental Sum of Square Attributed to Added Variable SS_3-SS_2'
x_3	5,525,370	10
x_4	5,527,820	2,460
x_5	5,526,750	1,390
x_6	5,525,940	580

The largest incremental sum of squares attributed to an independent variable is 2,460, associated with the variable x_4.

$$F \text{ (calculated)} = \frac{2460 \times (19-1)}{152,230} = 0.31$$

$$F_{.05;18,1} = 4.25$$

Hence, variable x_4 is not significant, terminating the process.

Following the same procedures for the hospitals in SMSA found no significant variable beyond x_1.

APPENDIX E

SUMMARY OF INFORMATION OBTAINED FROM MANUFACTURERS OF HOSPITAL SOLID WASTE HANDLING SYSTEMS

Over 200 manufacturers of components of hospital solid waste handling systems were contacted to obtain current (1971-1972) capital cost estimates. They were also asked to provide descriptive and technical information which was useful in establishing minimum performance standards for the different systems. The list of manufacturers contacted was developed from trade and equipment journals and from a list provided in a previous study of waste handling systems.[10]

Table E.1 shows the number of manufacturers contacted, the means of contact, the number of manufacturers responding, and the number of responses which included cost information. Manufacturers of incinerators and compactors provided a considerable amount of technical and capital cost information which is summarized in Tables E.2 and E.3, respectively.

TABLE E.1

SUMMARY OF CONTACTS WITH MANUFACTURERS OF HOSPITAL SOLID WASTE HANDLING SYSTEMS

Product of manufacturer	No. of manufacturers contacted		No. of manufacturers responding			No. of responses which include cost information	
	by letter	by other means	to letter	to other means	not applicable**	from letter	from other means
Paper, plastic liners	12(2)		5(1)	1	1	3	1
Carts, receptacles	16(3)	7	6(1)	9		5	3
Can washers	3(1)			1			1
Gravity chutes	9		1		5	1	
Pneumatic chutes	3(1)		3(1)			1	
Wet pulpers	4(2)		1	2	1	1	
Automated conveyance systems	33(4)		8(2)	2	4		
Shredders, hammermills	16(4)	2	10(2)	4		2	2
Can/bottle/needle crushers	7(2)	1	5	2	1	2	1
Wet grinders	10(2)	2	4	3	2	1	1
Balers	8(2)	1	3(1)	2		3	1
Compactors	25(16)	11	11(5)	22		8	7
Incinerators	27(11)	7	13(4)	14	1	12	1
TOTAL	173(50)	31	70(17)	62	15	39	18

* Numbers in parenthesis refer to the number of companies which were contacted by and/or responded to both the letter and other means of contact. The other means of contact include previous correspondence, advertising referrals in magazines, telephone conversations and personal visits.

** Manufacturers indicated that their systems were not applicable to hospital solid waste handling.

TABLE E.2

SUMMARY OF INFORMATION OBTAINED FROM INCINERATOR MANUFACTURERS

Incinerator capacity (lb./hr.)				Cost	Size of afterburner	Stack height supplied**	Size of auxiliary burner	Auxiliary burners available	
Type 0	Type 1	Type 2	Path.		(10^6 BTU/hr.)	(ft.)	(10^6 BTU/hr.)	10^6BTU/hr.	cost
Mixture 95 - 125				$3,166	.125	10	N/A$^\#$	.075-.25	$440
Mixture 100 - 150				$5,400*	N/D$^+$	N/D	N/D		
Mixture 150 - 250				$4,015	.125	8	N/A	.075-.25	$440
115	155	230	100	$4,400	.25	10	.25		
Mixture 265				$4,724	.05	16	N/A		
Mixture 200 - 250				$9,900*	N/D	N/D	N/D		
150	200	300		$4,200	.2	12	N/A	.2	$500
170	220	320	300	$7,900	.25	8	.25		
130	190	250	400	$9,000	.05 - .6	8	.05 - .6		
Mixture 250				$8,075	.075	15	N/A		
Mixture 300 - 370				$16,700*	N/D	N/D	N/D		
Mixture 300 - 400				$7,497	.125	8	N/A	.075-.25	$440
Mixture 315				$10,275	.075	15	N/A		
Mixture 400				$12,700*	N/D	15	N/A		
300	400	550		$5,300	.3	12	N/A	.2	$500
Mixture 400				$19,900*	N/D	15	N/A		
225	450	225		$13,230*	.05	10	N/A		
Mixture 475				$15,395	.15	15	N/A		
375	490	575	250	$12,750	N/D	0	N/A	1.2	$870
Mixture 500 - 620				$32,000*	N/D	N/D	N/D		
Mixture 500 - 600				$10,570	.125	8	N/A	.25-.5	$575
	500			$13,000	N/D	0	N/A		
420	550	800	800	$19,000	.05 - 1.2	8	.05 - 1.2		
Mixture 600				$15,500*	N/D	15	N/A		
450	600	775		$6,970	.4	12	N/A		
400	600	500		$18,060*	.075	20	N/A		
Mixture 600				$23,900*	N/D	15	N/A		
Mixture 650				$18,295	.15	15	N/A		
Mixture 700 - 800				$12,525	.125	8	N/A	.25-.5	$575
575	735	900	375	$15,950	N/D	0	1.2	2.5	$400
	750			$15,000	N/D	0	N/A		

TABLE E.2 (Continued)

Incinerator capacity (lb./hr.)				Cost	Size of afterburner	Stack height supplied**	Size of auxiliary burner	Auxiliary burners available	
Type 0	Type 1	Type 2	Path.		(10^6 Btu/hr.)	(ft.)	(10^6 Btu/hr.)	10^6 BTU/hr.	Cost
Mixture 800				$18,200*	N/D	15	N/A		
600	800	1000		$9,150	.5	12	N/A	.5	$570
Mixture 800				$27,900*	N/D	15	N/A		
Mixture 840				$19,395	.15	15	N/A		
600	900	1350	1300	$21,000	.05 - 1.2	8	.05 - .6		
750	975	1200	500	$19,800	2.3	0	1.2	2.5	$400
Mixture 1000 - 1200				$44,500*	N/D	N/D	N/D		
750	1000	1250		$13,150	.6	12	N/A	.6	$700
	1000			$18,500	N/D	0	N/A		
Mixture 1050				$21,450	.15	15	N/A		
Mixture 1200 - 1500				$23,775	2(.125)	8	N/A		
900	1200	1600		$17,150	.7	12	N/A	.7	$700
600	1200	1000		$26,880*	.15	20	N/A		
1125	1475	1600	750	$25,630	4.6	0	1.2	2.5	$400
Mixture 1500 - 1800				$58,000*	N/D	N/D	N/D		
	1500			$21,500	N/D	0	N/A		
1500	1950	2300	1000	$32,950	4.6	0	2.5	4.5	$830
Mixture 2000 - 2300				$79,000*	N/D	N/D	N/D		
	2000			$28,000	N/D	0	N/A		
Mixture 2000				$85,000	N/D	N/D	N/D		
Mixture 2500 - 2900				$89,000*	N/D	N/D	N/D		
Mixture 6000				$120,000	N/D	0	N/D		

* Cost includes cost of automatic feeding device.
** Amount of stack provided by the manufacturer as part of the purchase price.
# Not applicable.
+ No data.

TABLE E.3

SUMMARY OF INFORMATION OBTAINED FROM COMPACTOR MANUFACTURERS

Horsepower		Cost	Hopper capacity (cu.ft.)		Cycle time (sec.)	Hopper opening (in. x in.)	Ram pressure		Ram stroke (in.)
							lbs.	psi	
.5		$2,400	1 plastic bag	3.5	N/D**	N/D	3,700	N/D	N/D
.5		$2,750	1 plastic bag	3.5	N/D	12 x 23	4,000	N/D	N/D
.5		$3,600	2 plastic bags	7.0	N/D	12 x 24	4,000	N/D	N/D
.5		$3,200	2 plastic bags	7.0	N/D	N/D	3,700	N/D	N/D
.5		$2,995	bags or boxes	7.5	N/D	24 x 18	16,000	N/D	N/D
.67		$2,995		N/D	N/D	N/D	N/D	N/D	N/D
.67		$2,995	1 plastic bag	3.9	30	N/D	4,900	42	N/D
1.0		$3,400		2.9	125	24 x 19	30,000	26	N/D
1.0	baler	$2,090	bales(36 x 20 x 26)		N/D	14 x 36	N/D	N/D	26
1.5		$4,070		6.3	165	24 x 23	32,000	19	N/D
1.5		$1,850	1 plastic bag	6.0	25	24 x 16	10,500	15	N/D
2.0		$4,500		5.0	N/D	24 x 23	N/D	N/D	31
3.0		$3,500		14.0	50	20 x 43	23,000	33	34
3.0	baler	$2,090	bales(36 x 20 x 26)		N/D	14 x 36	N/D	N/D	26
3.0		$4,000		9.0	N/D	24 x 24	42,000	16	N/D
3.0		$4,000		14.0	20	30 x 23	7,070	10	30
3.0		$3,600		17.0	20	36 x 23	7,070	10	30
5.0		$2,675		27.0	25	37 x 30	22,620	N/D	N/D
5.0		$4,400		10.8	23	24 x 24	20,000	30	34
5.0	baler	$2,865		7.0	15	20 x 30	N/D	N/D	N/D
5.0		$4,600		8.9	N/D	24 x 24	65,000	135	25
5.0	baler	$2,575	bales(45 x 24 x 29)		N/D	16 x 45	N/D	N/D	29
5.0	baler	$2,965		7.0	15	20 x 30	N/D	N/D	N/D
7.5		$4,400		8.1	28	18 x 24	14,000	60	44
7.5		$4,200		33.8	59	54 x 40	49,500	32	52
7.5	baler	$4,250	bales(54 x 26 x 34)		N/D	18 x 54	N/D	N/D	34
7.5		$4,200		33.8	59	54 x 40	49,500	32	52
7.5		$5,400		67.5	57	53 x 76	49,500	32	88
10.0		$7,300*		33.8	72	54 x 40	49,500	32	52
10.0		$3,375		51.3	35	54 x 38	41,140	N/D	N/D
10.0		$4,900		48.6	35	60 x 30	34,000	32	56
10.0		$4,900		N/D	N/D	N/D	N/D	N/D	N/D
10.0		$8,500*		67.5	63	54 x 76	49,500	32	88
15.0		$5,850		72.9	40	60 x 48	62,830	N/D	N/D
15.0		$6,600		81.0	50	56 x 42	50,893	28	80

* Unit has double compacting feature. Waste is compacted in the hopper prior to being compacted in the container.

** No data

APPENDIX F

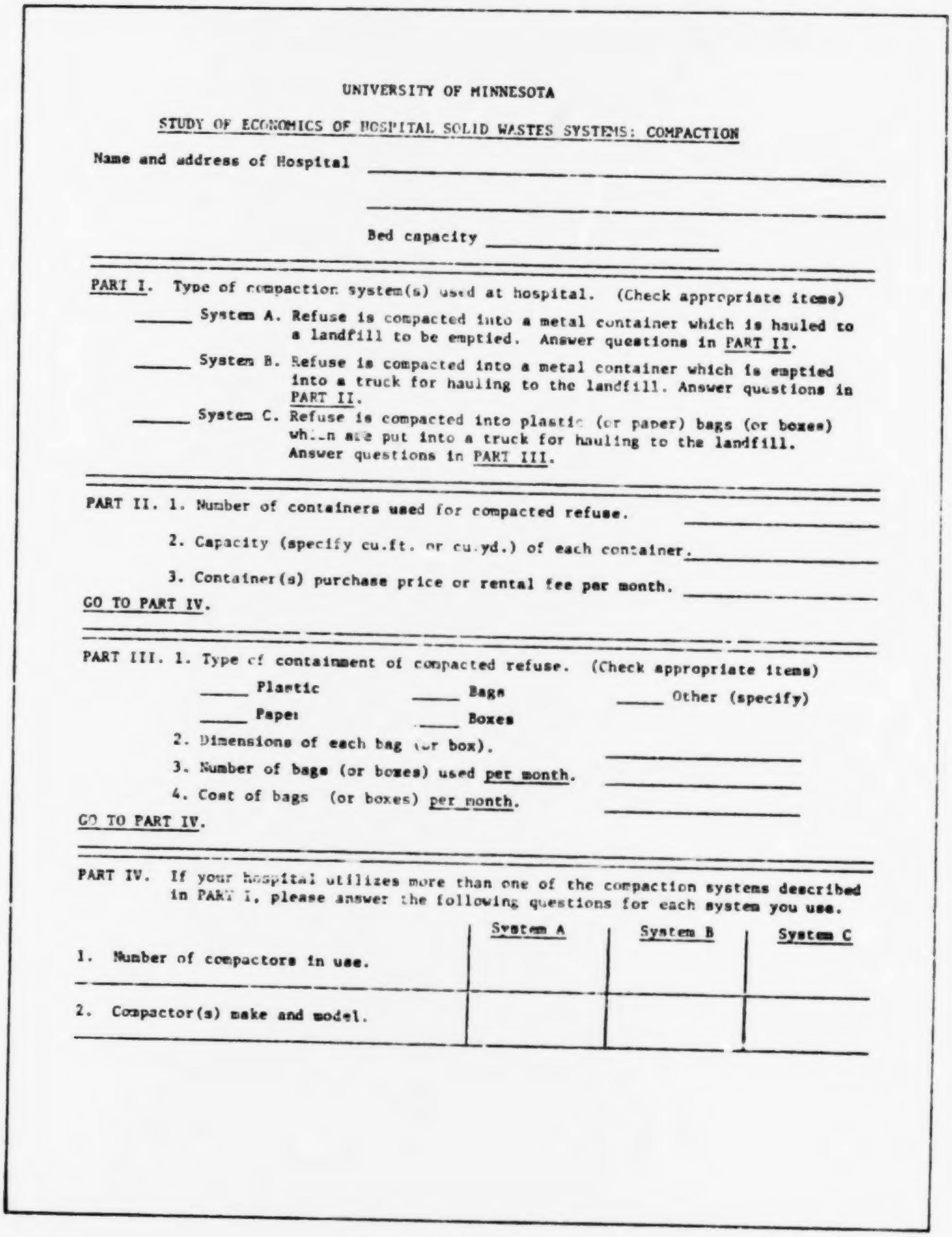
SUMMARY OF INFORMATION OBTAINED FROM HOSPITALS CONCERNING THEIR SOLID WASTE HANDLING SYSTEM

Hospitals were contacted to obtain information on the actual capital and operating costs associated with different hospital solid waste handling systems. In the early stages of the study, personal visits were made to several hospitals to observe the systems in operation. Interviews with administrative, engineering and maintenance personnel provided information on the factors affecting the costs of the systems, as well as limitations and problems associated with the various systems.

With this information and information provided by manufacturers, questionnaires were developed for four solid waste handling systems; compaction, incineration, pneumatic tube and pulping. Copies of and responses to the questionnaires are given in Tables F.1-F.9.
The list of hospitals which received a questionnaire was provided by equipment manufacturers.

TABLE F.1

QUESTIONNAIRE ON HOSPITAL SOLID WASTE COMPACTION SYSTEMS



UNIVERSITY OF MINNESOTA

STUDY OF ECONOMICS OF HOSPITAL SOLID WASTES SYSTEMS: COMPACTION

Name and address of Hospital ______________________________

____

Bed capacity ______________

PART I. Type of compaction system(s) used at hospital. (Check appropriate items)

- ______ System A. Refuse is compacted into a metal container which is hauled to a landfill to be emptied. Answer questions in PART II.
- ______ System B. Refuse is compacted into a metal container which is emptied into a truck for hauling to the landfill. Answer questions in PART II.
- ______ System C. Refuse is compacted into plastic (or paper) bags (or boxes) which are put into a truck for hauling to the landfill. Answer questions in PART III.

PART II. 1. Number of containers used for compacted refuse. ______________

2. Capacity (specify cu.ft. or cu.yd.) of each container. ______________

3. Container(s) purchase price or rental fee per month. ______________

GO TO PART IV.

PART III. 1. Type of containment of compacted refuse. (Check appropriate items)

_____ Plastic　　_____ Bags　　_____ Other (specify)

_____ Paper　　_____ Boxes

2. Dimensions of each bag (or box). ______________

3. Number of bags (or boxes) used per month. ______________

4. Cost of bags (or boxes) per month. ______________

GO TO PART IV.

PART IV. If your hospital utilizes more than one of the compaction systems described in PART I, please answer the following questions for each system you use.

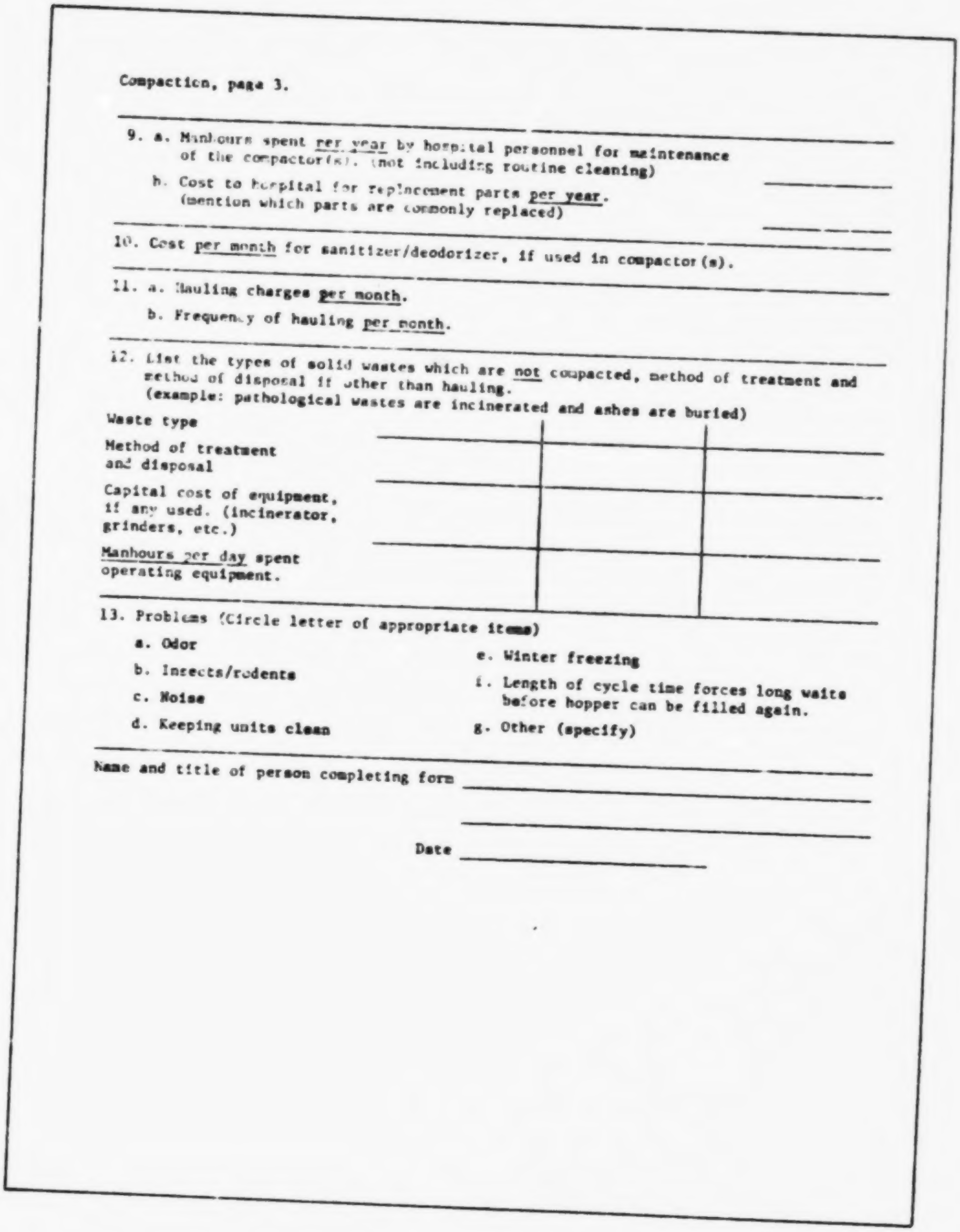
	System A	System B	System C
1. Number of compactors in use.			
2. Compactor(s) make and model.			

TABLE F.1 (Continued)

Compaction, page 2.

	System A	System B	System C
3. a. Total weight of refuse generated in hospital per day ________.			
b. Weight of refuse compacted per day.			
4. a. Horsepower of motors in each compactor.			
b. Hopper capacity of each compactor. (Specify cu.ft. or cu.yd.)			
5. Year of installation.			
6. Total capital cost. (Please break down costs as follows)			
a. Compactor purchase price or rental fee per month.			
b. Installation charge, if not included in item 6.a.			
c. Utility hook-up cost, if not included in one of the above two categories. Otherwise indicate which item includes this cost.			
d. Cost of building modification or construction of facilities to house compactor(s), if not included in one of the above categories. Otherwise indicate which item includes this cost.			
7. Method of charging waste into compactor hopper. (Check appropriate items)			
a. Manual charging bag by bag	a.___	a.___	a.___
b. Manual dumping of cart into hopper	b.___	b.___	b.___
c. Automatic loader dumps contents of cart into hopper	c.___	c.___	c.___
d. Gravity chute (or pneumatic system) drops waste directly into hopper	d.	d.	d.
e. Other (specify)			
8. a. If waste is manually charged into compactor hopper, indicate daily manhours spent performing this task			
b. If automatic loader used, indicate the cost, if not included in item 6.a. (equipment costs)			
c. Daily manhours spent cleaning compactor area.			

TABLE F.1 (Continued)



Compaction, page 3.

9. a. Manhours spent per year by hospital personnel for maintenance of the compactor(s). (not including routine cleaning)

   b. Cost to hospital for replacement parts per year. (mention which parts are commonly replaced)

10. Cost per month for sanitizer/deodorizer, if used in compactor(s).

11. a. Hauling charges per month.

   b. Frequency of hauling per month.

12. List the types of solid wastes which are not compacted, method of treatment and method of disposal if other than hauling. (example: pathological wastes are incinerated and ashes are buried)

Waste type			
Method of treatment and disposal			
Capital cost of equipment, if any used. (incinerator, grinders, etc.)			
Manhours per day spent operating equipment.			

13. Problems (Circle letter of appropriate items)

   a. Odor

   b. Insects/rodents

   c. Noise

   d. Keeping units clean

   e. Winter freezing

   f. Length of cycle time forces long waits before hopper can be filled again.

   g. Other (specify)

Name and title of person completing form

Date

TABLE F.2

SUMMARY OF RESPONSES TO THE COMPACTION QUESTIONNAIRE
FROM SEVEN HOSPITALS OF THE 25 HOSPITALS CONTACTED

Hospital	1	2	3		4		5		6	7
Bed capacity	500	177	503		1040		1100		304	365
Type of system*	A	A	A	C	A	C	A	C	A	B
Part II										
No. of containers	1	1	1	N/A	N/D	N/A	2	N/A	1	1
Capacity(cu.yd.)	27	20	32	N/A	N/D	N/A	40	N/A	35	8
Purchase price or rental fee	N/D#	$212/mth	N/D	N/A	N/D	N/A	$88/mth	N/A	$330/mth**	$171/mth**
Part III										
Type of containment	N/A+	N/A	N/A	plastic bags	N/A	bales/wire	N/A	plastic bags	N/A	N/A
Dimensions(cu.ft.)	N/A	N/A	N/A	2(3.5)	N/A	10	N/A	2(3.5)	N/A	N/A
Monthly use	N/A	N/A	N/A	N/D	N/A	750	N/A	900	N/A	N/A
Cost/month	N/A	N/A	N/A	N/D	N/A	N/D	N/A	$180	N/A	N/A
No. of compactors	1	1	1	2	1	6	1	8	1	1
H.P. of motors	0.5	25	10	0.25	25	5	20.5	N/D	15	5
Hopper capacity (cu.yd.)	0.6	1.25	3	0.12	1.5	0.5	3	0.12	3	1
Lbs/day of solid waste generated in hospital	4,750	N/D	N/D		6,000		N/D		18,610	8,000
Lbs/day compacted	3,500	1,500	N/D	N/D	N/D	N/D	N/D	N/D	18,610	6,000
Year of installation	1968	1969	1968	1970, 71	1971	1969	1971	1971	1971	1969
Capital cost breakdown										
Purchase price	$9,000	$7,783	$8,000	$3,600 $4,100	$22,000	$3,500/unit	$8,062	$3,200/unit	N/A	N/A
Monthly rental fee	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	$330	$171
Installation costs	N/D	N/D	N/D	$175	N/D		$1,200	N/D	N/D	$0
Utility hook-up costs	$350	N/D	$525	N/D	$3,000	} $600/unit	$300	N/D	$0	$165
Construction costs	$0	N/D	$0	$0	N/D		$36,838	N/D	$0	$50
Method of charging	manual	manual	manual	manual	fork lift truck		automatic loader	manual	manual	manual
Daily charging manhours	4	2	3	1	8	16	6	N/D	2	} 8
Daily cleaning manhours	0.67	0.5	0.5	N/D	1.0	0.5	3.0	2.0	1.0	
Yearly maintenance manhours	30	24	10		20		none to date		maintenance by contractor	none to date
Yearly cost of parts	$20	N/D	N/D	no parts replaced	$100					
Parts replaced	shackles	N/D	pressure gage, switch		N/D					
Sanitizer/deodorizer cost/month	N/D	$5	$3200		$33		$11		N/D	$12
Monthly hauling charges	$950	$150	$1200		$80		$528		included in rent	$450
Frequency of hauling per month	12	4-5	16		24		6		6	30
Treatment and disposal of other waste	Path. burned	Path. to landfill	Path. burned		path. burned, $15,000 incinerator		path. burned in two incinerators		path. burned	paper burned $26,000 incin.
Problems with compactor	odor, wet waste, keeping units clean	odor	noise, keeping units clean		odor, keeping units clean, insects/rodents		odor, keeping units clean, insects/rodents, winter freezing		noise during loading/unloading	odor, keeping units clean

*Type of system: System A: Refuse is compacted into a metal container which is hauled to a landfill to be emptied.
System B: Refuse is compacted into a metal container which is emptied into a truck for hauling to the landfill.
System C: Refuse is compacted into plastic(paper) bags(boxes) which are put into a truck for hauling to the landfill.

**Includes rental fee for compactor

# No data

+ Not applicable

TABLE F.3

QUESTIONNAIRE ON HOSPITAL SOLID WASTE INCINERATION SYSTEMS

UNIVERSITY OF MINNESOTA

STUDY OF ECONOMICS OF HOSPITAL SOLID WASTES SYSTEMS: INCINERATION

Name and address of Hospital ______________________________

____

Bed capacity ______________

1. Number of incinerators in use ______________.

If more than one incinerator, supply the following data for each

	INCINERATOR 1	INCINERATOR 2	INCINERATOR 3
2. Incinerator rated capacity (lb./hr.)			
3. Incinerator make and model.			
4. Solid wastes sent to incinerator. (Check those applicable) a. Burnables b. Burnables & nonburnables c. Infectious & pathological d. Pathological only e. Needles & syringes	a. ____ b. ____ c. ____ d. ____ e. ____	a. ____ b. ____ c. ____ d. ____ e. ____	a. ____ b. ____ c. ____ d. ____ e. ____
5. Method of waste collection and transport to incinerator. (Check appropriate items) a. Manual collection and transport b. Gravity chutes c. Pneumatic system d. Other (specify)	a. ____ b. ____ c. ____ d.	a. ____ b. ____ c. ____ d.	a. ____ b. ____ c. ____ d.
6. Method of charging waste into incinerator. (Check appropriate items) a. Manual charging b. Manual charging into automatic loader c. Complete automatic loading d. Other (specify)	a. ____ b. ____ c. ____ d.	a. ____ b. ____ c. ____ d.	a. ____ b. ____ c. ____ d.
7. No. of hours of incinerator operation per day on: a. weekdays. b. weekends.	a. ____ b. ____	a. ____ b. ____	a. ____ b. ____

TABLE F.3 (Continued)

Incineration, page 2.

	INCINERATOR 1	INCINERATOR 2	INCINERATOR 3
8. a. Total weight of waste generated in hospital per day ________________.			
b. Weight of waste incinerated per day	b. _____	b. _____	b. _____
9. a. Year of installation.			
b. Indicate if installed in a new or existing hospital.			
10. Total capital cost. (Please break down costs as follows)			
a. Equipment cost (equipment and accessories delivered to site).			
b. Installation charge, if not included in item 10.a.			
c. Utility hook-up cost, if not included in one of the above two categories. Otherwise indicate which item includes this cost.			
d. Cost of building modification or construction of facilities to house incinerator, if not included in one of the above categories. Otherwise indicate which item includes this cost.			
11. a. If waste is fed manually to a loader or incinerator, indicate daily manhours spent performing this task.			
b. If automatic loader used, indicate the cost, if not included in item 4.a. (equipment cost)			
c. Daily manhours spent cleaning each incinerator.			
12. Utility costs per month*			
a. Gas			
b. Electricity			
c. Other (water, etc.)			

---

* If costs cannot be estimated from records or supplier literature, please indicate the size of the burner(s) (BTU/hr), and the h.p. of any motors in the incinerators.

TABLE F.3 (Continued)

Incineration, page 3.

13. a. Manhours spent per year for maintenance of incinerator(s). (not including routine cleaning) ____________

b. Cost of replacement parts per year. (mention which parts are commonly replaced) ____________

14. Indicate the number of times during the last year when the incinerator broke down to the extent that it could not be used for more than four hours. ____________

Indicate how accumulated waste is handled while the incinerator is shutdown for repairs.

15. a. Cost of hauling ashes and other trash per month. ____________

b. Number of trash pickups per month. ____________

c. Size (specify cu.yd. or cu.ft.) of container(s) ____________

16. List the types of solid wastes which are not sent to any of the incinerators, method of treatment and method of disposal if other than hauling. (Example: cans and bottles sent through can/bottle crusher)

Waste type			
Method of treatment and disposal			
Capital cost of equipment, if any used. (can crusher, syringe/needle oven, etc.)			
Manhours per day spent operating equipment.			

Name and title of person completing form ____________

Date ____________

TABLE F.4

SUMMARY OF RESPONSES TO THE INCINERATION QUESTIONNAIRE
FROM 24 HOSPITALS OF THE 42 HOSPITALS CONTACTED

Hospital	Bed capacity	Incinerator capacity (lbs/hr)	Year of installation, new or existing hosp.	Capital cost breakdown: Equipment cost	Capital cost breakdown: Installation cost	Capital cost breakdown: Utility hook-up cost	Capital cost breakdown: Construction cost	Lbs/day of solid waste: Generated in hospital	Lbs/day of solid waste: Incinerated	Waste incinerated*	Method of collection and transport	Method of charging	Hours of operation on: Weekdays	Hours of operation on: Weekends
1	264	625	1969E	$9,050	$350	in install. cost	$1,200	1,600	1,200	a	manual	manual	12	16
2	384	600	1970E	$17,500	$6,500	$1,500	$3,800	N/D **		b,c,e	manual gravity chutes	manual	10	10
3	525	300	1971E	$51,000(includes inst.,util.)			$4,634	N/D	300-400	c	manual	manual	3	0
4	334	600	1969E	$11,500				3,500	2,300	a,c	manual gravity chutes	manual	6	6
5	200	300	1967N	$10,000				1,200	750	a,c	manual	manual	5	5
6	340	600	1971E	$16,000			$10,000	N/D	N/D	b,e	manual	manual	8	4
		13	1960E	N/D					N/D	d	manual	manual	4 hr/2 wks	
7	163	525	1969E	$3,500	$45	$150	$75	1,000	800	a,c,e	manual	manual	6	4
8	180	800	1970E	$18,000 (loader) #				N/D		b,c,e	manual	manual into loader	8	8
9	58	330-525	1970E	$5,000	$114	$265	$393	400	400	b,c,e	manual	manual	16 hr/wk	
10	486	300	1967N	$28,550				3,000	750	b,c,e	manual	manual	8	8
		75	1963N	$20,000					20	d	manual	manual	16 hr/wk	
11	331	750	1966N	$12,000				7,500	4,500	b,c	manual gravity chutes	manual	12	8
		100	1958N	$4,000					20	d	gravity chutes	manual	1	N/D
12	290	625	1968E	$11,200 (includes install.)		$125		2,410	2,410	a,c	manual	manual	6.5	6.5
13	200	566	1968E	$9,330			$2,355	2,000	1,000	a,c	manual	manual	6	6
14	389	1150-1875	1970E	$24,839(loader)	$300		0	4,300	4,500	b,c,e	manual	manual into loader	3	3
15	2437	N/D	1971E	$185,000 (loaders)				6,900	3,300	b,e	manual	manual into loader	6	N/D
		N/D							3,300	b,e	manual	manual into loader	6	N/D
16	210	500	1968N	$44,000(loader)			$15,000	2,500	1,800	a,c,e	manual gravity chutes	manual into loader	5	5
17	984	150	1967N	$6,680 (includes inst., util, & const)				15,000	175	d	manual	manual	4	4
		500	1968E	$22,000 (includes inst., util., const. & loader)					3,000	b,c,e	manual	manual into loader	8	8
		500	1968E	$22,000 (includes inst., util., const. & loader)					3,000	b,c,e	manual	manual into loader	8	8
18	357	800	1971E	$12,627(loader)	$560		$2,884	N/D	2,150	a,c	manual	manual into loader	10	0
19	404	N/D	1964N	N/D				2,500	1,400	a,c,e	manual gravity chutes	manual	8	8
20	416	625	1970N	$21,800				(50 cu.yd)	200	a,d	manual	manual	N/D	2
21	600	1500	1966N	N/D				N/D	4,000	a,c	manual gravity chutes	manual	10	8
22	450	600	1969E	$14,895 (includes inst. & const.)		$180		4,100	380	a,c,e	manual	manual	17	17
23	194	330-525	1970N	$6,200				6,000	600	a,c	manual	manual	4	2
24	660	360	1962	$7,700			$10,830	N/D	690	c	manual	manual	5	0

*Wastes incinerated: a. burnables, b. burnables and nonburnables, c. infectious and pathological, d. pathological only, e. needles and syringes.
**No data
#Incinerator equipment cost includes the cost of an automatic loader.

TABLE F.4 (Continued)

Hospital	Utility costs or size of burner (million BTU/hr) and h.p. of motor in brackets: Gas	Elec.	Other	Daily charging manhours	Daily cleaning manhours	Maintenance: Yearly maintenance manhours	Yearly cost of replacement parts	Parts replaced	No. of breakdowns/yr exceeding four hours	What is done with waste during breakdown	Hauling: Monthly hauling cost	Pick-ups/month	Size of containers (cu.yd.)	Treatment and disposal of other waste
1	$20	$10		6.0	1.0	40	$400	gaskets, smoke screen	2	hauled	$75	9	8	cans/glass hauled
2	$138	[1]		10.0	2.5	24	$200		1	hauled	$108	14	8	cans/glass hauled
3	[.6,.5]	[.5, 2(.05)]		1.0	1.0	in operation one month			0	hauled	$525*	7	10	all but infec./path. compacted & hauled
4	[1]	[3]		6.0	0.33	48	$700	gaskets, locks, dampers, refrac	2	hauled	$183	26	1	N/D
5	N/D	[5, 2(.33)]		1.5	1.0	N/D	$1,800	parts & labor	0	N/D	$52	12	4	noncombus. hauled
6	$150 $20	N/D N/D		---- 8 ---- 4 hr/2 wks.		40 still on warranty			1	hauled	$150	4	3	cans/bottles crushed & hauled
7	N/D	N/D		6.0	1.0	6	$75		0	N/D	$50	use own truck		cans/bottles hauled
8	N/D	N/D		8.0	1.0	10	none as yet		0	N/D	0	8	8	cans/bottles hauled
9	$35	[2.5]		0.5	N/D	N/D	none as yet		0	N/D	0	8	N/D	everything to incinerator
10	[.5,.05] [.5,.075]			1.5 0.25	N/D N/D	42	$427	hoses, burner, switches	2	stored in incinerator	0	20	15	ashes and other wastes hauled
11	$40 $2	$5 negligible		11.0 1.0	1.0 1 hr/wk	32	$200	door cables, refractory, burner parts	0	hauled	$400	120	3	needles/syringes, some plastics ground to sewer
12	[1]	[3]		3.0	0.5	12	$97	gaskets	N/D	N/D	$92	14	N/D	N/D
13	[1]	[2(3)]		4.0	1.5	52	$300	gaskets	0	N/D	$80	4	1.5	N/D
14	[.35,.2]			3.0	0.67	N/D			0	N/D	$50	12	N/D	N/D
15	[.6,2(.25)] [.6,2(.25)]			8.0 8.0	2.0 2.0	under free service			2	hauled	$384	200	16	N/D
16	$90	$23	$115	2.0	0.5	114	$575	spark plugs, scanners, lens	11	hauled	$ 45	26	2	N/D
17	$48 $144 $144	$1 $22 $22	$1 $10 $10	1.0 3.5 3.5	0.25 0.5 0.5	N/D	$1,063	parts & labor	2	to other incinerator or hauled	$685	N/D	30	cardboard sold to contractor. cans/bottles sold to city for recycling
18	[2(.5)]	[2,3]		4.0	1.0	none as yet			2	burned in open pit	N/D	22	N/D	cans/bottles crushed & buried
19	N/D	N/D		6.0	2.0	40	$150	misc. parts	0	N/D	$500	30	N/D	all waste not burned is hauled away
20	[.4]	[3]		1.0	1 hr/wk	N/D			N/D	N/D	$750*	5	40	nonburnables compacted
21	$100	$20		8.0	1.0	100	$100	refractory, spray nozzles	2	hauled	$125	52	4	cans/bottles crushed & hauled with plastics
22	[1]	N/D		16.0	1.5	8-10	$233	thermocouples	1	N/D	0	8-10	8	cans/bottles crushed & hauled with plastics
23	N/D	N/D		1,0	1,0	12	$10		0	hauled	$20	2	14	cans/bottles hauled
24	[.75,.5]	[.025]		7.0	1.0	24	$60	grates	0	N/D	$885*	16	40	all waste not burned is compacted

*Includes compactor rental fee.

TABLE F.5

QUESTIONNAIRE ON HOSPITAL PNEUMATIC TUBE WASTE COLLECTION SYSTEMS

UNIVERSITY OF MINNESOTA

STUDY OF ECONOMICS OF HOSPITAL SOLID WASTES SYSTEMS: PNEUMATIC SYSTEM

Name and address of Hospital ____________________

____

Bed capacity __________

1. Make of unit or name of manufacturing company.

2. Type of pneumatic system (Circle letter of appropriate items)
   - a. Gravity chute - pneumatic
   - b. Total pneumatic
   - A. For trash only
   - B. For linen only
   - C. For linen and trash (indicate if single or double tube)

3. Number of charging stations.
   - a. For trash only ________
   - b. For linen only ________
   - c. For linen and trash ________ (in the case where there is a single charging door for both trash and linen)

4. a. Diameter of tube (in.) ______
   - b. No. of vertical risers ______
   - c. Total length of tube (ft.) ______
   - d Length of horizontal run (ft.) ______

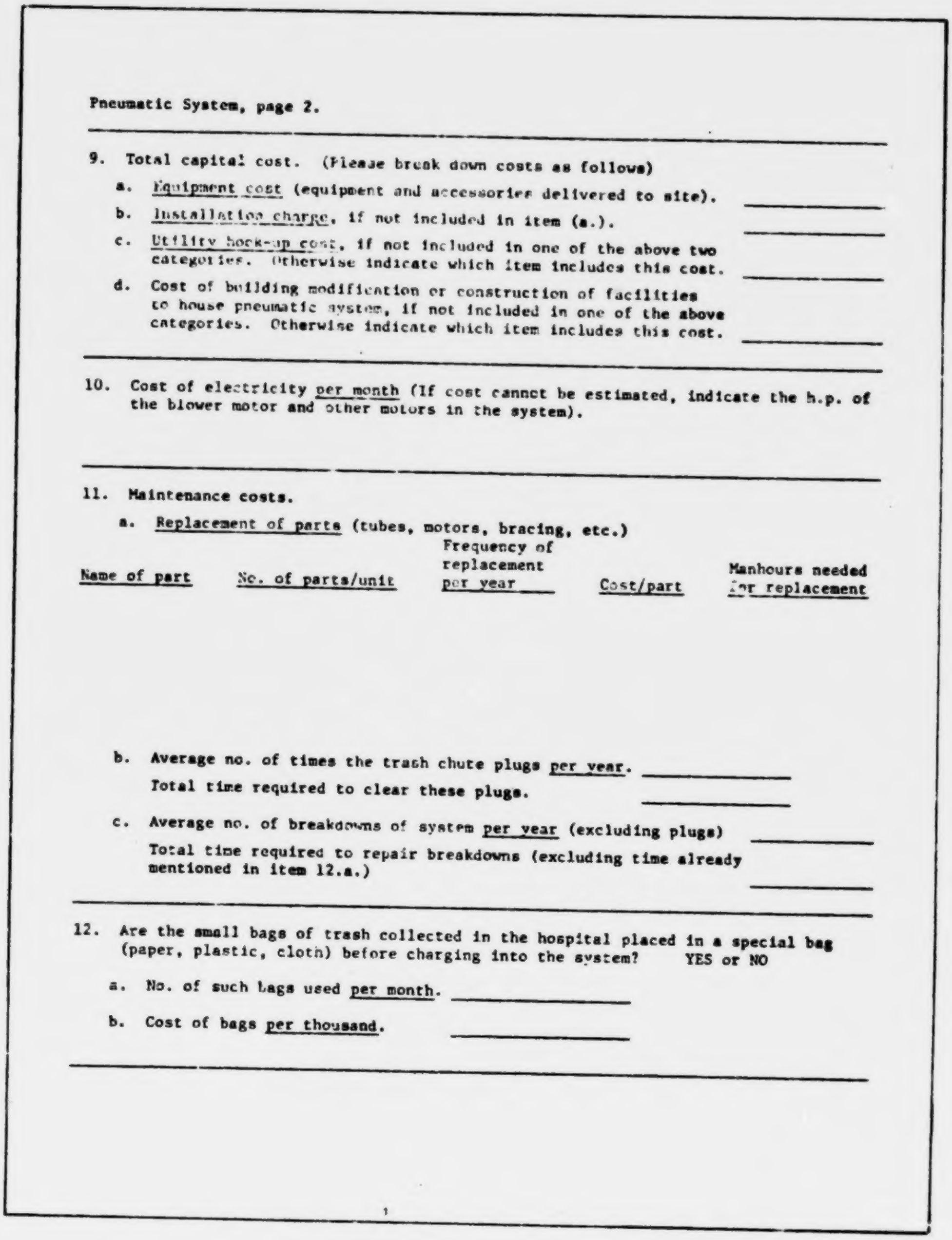
5. a. Total weight of trash generated in hospital per day. ________
   - b. Weight of trash going through pneumatic system per day. ________

6. No. of hours of pneumatic system operation per day on: weekdays ________
   weekends ________

7. Manhours spent on routine cleaning of system per week.

8. a. Year of installation.
   - b. Indicate if installed in new or existing hospital.

TABLE F.5 (Continued)



Pneumatic System, page 2.

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9. Total capital cost. (Please break down costs as follows)
   a. Equipment cost (equipment and accessories delivered to site). ________
   b. Installation charge, if not included in item (a.). ________
   c. Utility hook-up cost, if not included in one of the above two categories. Otherwise indicate which item includes this cost. ________
   d. Cost of building modification or construction of facilities to house pneumatic system, if not included in one of the above categories. Otherwise indicate which item includes this cost. ________

---

10. Cost of electricity per month (If cost cannot be estimated, indicate the h.p. of the blower motor and other motors in the system).

---

11. Maintenance costs.
   a. Replacement of parts (tubes, motors, bracing, etc.)

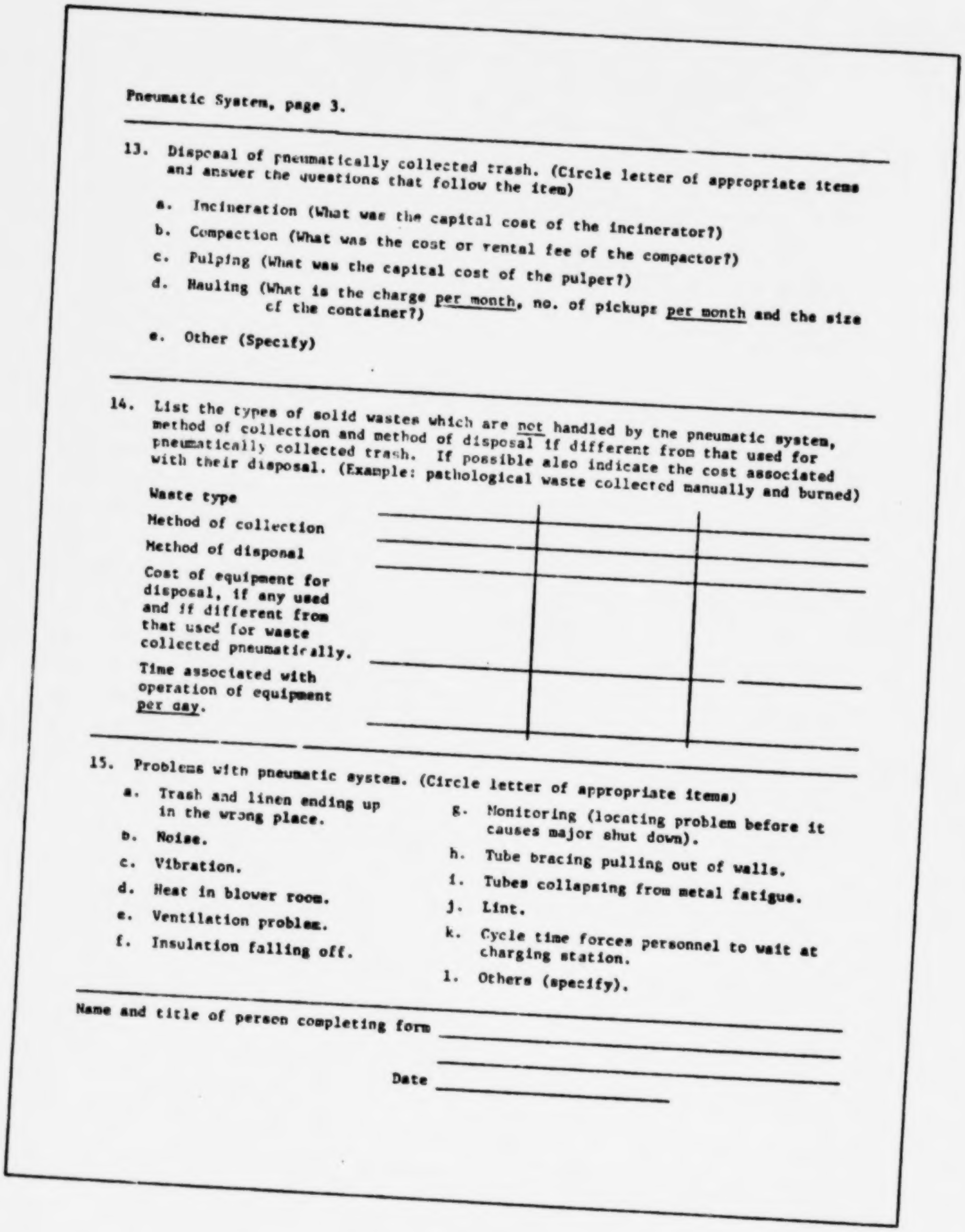
Name of part	No. of parts/unit	Frequency of replacement per year	Cost/part	Manhours needed for replacement

   b. Average no. of times the trash chute plugs per year. ________
   Total time required to clear these plugs. ________
   c. Average no. of breakdowns of system per year (excluding plugs) ________
   Total time required to repair breakdowns (excluding time already mentioned in item 12.a.) ________

---

12. Are the small bags of trash collected in the hospital placed in a special bag (paper, plastic, cloth) before charging into the system? YES or NO
   a. No. of such bags used per month. ________
   b. Cost of bags per thousand. ________

TABLE F.5 (Continued)



Pneumatic System, page 3.

13. Disposal of pneumatically collected trash. (Circle letter of appropriate items and answer the questions that follow the item)
    - a. Incineration (What was the capital cost of the incinerator?)
    - b. Compaction (What was the cost or rental fee of the compactor?)
    - c. Pulping (What was the capital cost of the pulper?)
    - d. Hauling (What is the charge per month, no. of pickups per month and the size of the container?)
    - e. Other (Specify)

14. List the types of solid wastes which are not handled by the pneumatic system, method of collection and method of disposal if different from that used for pneumatically collected trash. If possible also indicate the cost associated with their disposal. (Example: pathological waste collected manually and burned)

Waste type			
Method of collection			
Method of disposal			
Cost of equipment for disposal, if any used and if different from that used for waste collected pneumatically.			
Time associated with operation of equipment per day.			

15. Problems with pneumatic system. (Circle letter of appropriate items)
    - a. Trash and linen ending up in the wrong place.
    - b. Noise.
    - c. Vibration.
    - d. Heat in blower room.
    - e. Ventilation problem.
    - f. Insulation falling off.
    - g. Monitoring (locating problem before it causes major shut down).
    - h. Tube bracing pulling out of walls.
    - i. Tubes collapsing from metal fatigue.
    - j. Lint.
    - k. Cycle time forces personnel to wait at charging station.
    - l. Others (specify).

Name and title of person completing form ______________________

Date ______________

TABLE F.6

SUMMARY OF RESPONSES TO THE PNEUMATIC SYSTEM QUESTIONNAIRE FROM 15 HOSPITALS OF THE 43 HOSPITALS CONTACTED

Hospital	Bed capacity	Type of system	No. of charging stations			Diameter of tube (in.)	No. of vertical risers	Total length of tube (ft.)	Length of horiz. run (ft.)	Year of installation*	Capital cost breakdown				Lbs/day of solid waste generated in hospital	Lbs/day sent through pneumatic system	Hours of operation on		Manhours/week for charging
			For trash	For linen	For trash & linen						Equipment cost	Installation cost	Utility hook-up cost	Construction cost			Weekdays	Weekends	
1	710	Total Pneu. Single Tube	3	3	N/A#	16	1	450	400	1971N	53,000	22,000	9,000	8,000	8,000	1,650	15	15	0
2	690	Total Pneu. Single Tube	28	28	N/A	16	3	1,935	1,340	1970N	183,922(total cost)				N/D+	N/D	21	21	21
3	209	Total Pneu. Single Tube	N/A	N/A	7	16	1	N/D	N/D	1968N	60,000(total cost)				2,290	880	15	15	1
4	311	Total Pneu. Single Tube	N/A	N/A	10	16	3	178	160	1972N	79,900(total cost)				N/D	N/D	24 hrs on demand		N/A
5	1300	Grav.-Pneu. Double Tube	28	11	N/A	24	2	960	350	1973N	430,000				50,000	10,000-14,000	24	24	N/A
6	80	Total Pneu. Single Tube	4	4	N/A	18	N/D	800	700	1971N	90,000				N/D	N/D	4	4	4
7	330	Total Pneu. Single Tube	14	13	N/A	16	2	600	360	1971N	132,600(total cost)				15,000	10,000	24	24	4
8	400	Total Pneu. Single Tube	N/A	15	N/A	18	3	100	30	1962N	N/D				N/A	N/A	24	24	1
9	205	Total Pneu. Single Tube	N/A	11	N/A	14	3	500	300	1967N	25,000				N/A	N/A	24	24	2
10	362	Total Pneu. Single Tube	16	14	N/A	16	3	N/D	N/D	1970NE	N/D				7,240	5,430	13	8	8
11	350	Total Pneu. Single Tube	N/A	N/A	12	16	4	650	375	1969N	90,000(includes inst. & util.)				2,000	800	16	16	3
12	N/D	Total Pneu. Single Tube	N/A	N/A	5	16	1	830	264	1970N	104,103				1,500	1,200	5	5	5
13	560**	Total Pneu. Single Tube	N/A	4	N/A	16	1	225	177	1971N	47,963(includes install.)		1,500		N/A	N/A	24	24	0
14	250	Total Pneu. Single Tube	N/A	N/A	11	16	3	450	200	1971NE	100,000				1,500	1,500	24	24	6
15	234	Total Pneu. Single Tube	N/A	N/A	6	18	4	650	500	1969N	32,000				50 cu.yd.	40 cu.yd.	16	16	2

---

*N: New hospital; NE: New and existing hospital

**System serves a 150 bed unit.

#Not applicable.

+No data.

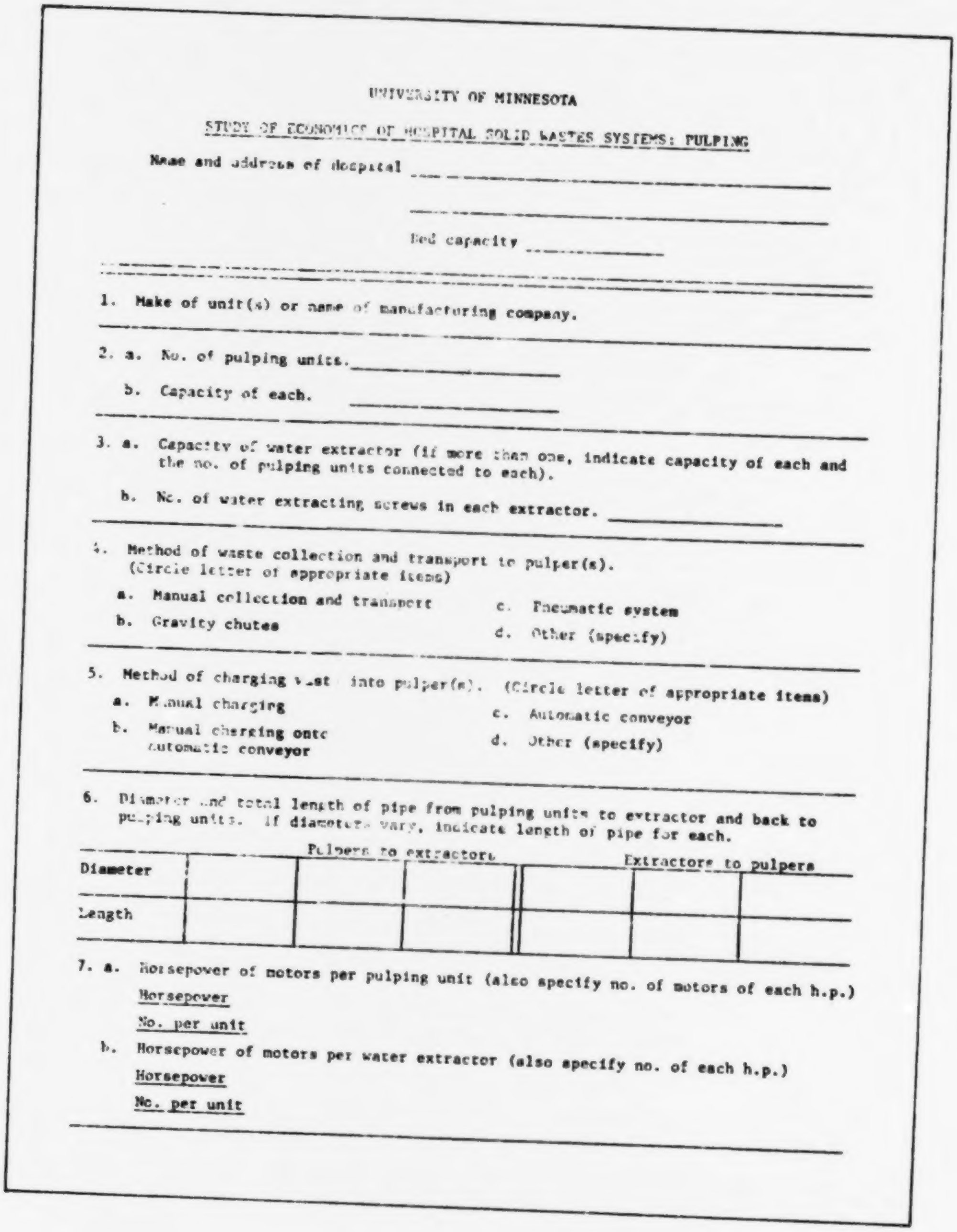
TABLE F.6 (Continued)

Hospital	Electricity cost/month or (h.p. of blower motor)	Parts replaced	Frequency of replacement/year	Cost/part	Manhours needed for replacement	No. of trash chute plugs/year	Total time to clear plugs	No. of system breakdowns/year	Total time to repair breakdowns	No. of bags used/month	Cost of bags/month	Disposal of waste transported by the pneumatic system	Disposal of other wastes	Problems with pneumatic system
1	(100)	None to Date				0	0	0	0	N/D	$40	INCINERATE in $8,000 unit	garbage - hauled	b,k
2	(125)	doors gaskets trash doors lub. dampers (weekly, monthly)	2 2	$10 reweld	4 8	17	20	12	36	26,500	$10	PULP($60,000) HAUL($486/month, 60/month)	diet. & adm. - pulped	a,d,g,j,k keeping screen c
3	(100)	o-ring for door door arm hinge	1 periodically		1 1/2	4	5	0	0	4,000	$50	PULP($23,000) HAUL($240/month, 12/month, 14 cu.yd.)	pathological incinerated	g,j
4	(75)	Not in Operation				N/A	N/A	N/A	N/A	Not in Operation		will incinerate and haul		Not Applicable
5	(200)	Not in Operation				N/A	N/A	N/A	N/A	Not in Operation		will incinerate ($265,000), compact(2 units - $20,000) and haul by municipality.		Not Applicable
6	(100)	None to Date				10	2	0	0	3,000	N/D	HAUL($15/month, 8 pickups/month)	cans/bottles -hauled	a,b,j,k
7	$1000	control relay door cylinder	5 2	$15 $50	1 2	12	2	24	1	6,000	$64	PULP($30,000) HAUL($90/month, 64/month,1 cu.yd.)	path.-burned, glass, diet. -hauled	a,b,c,d,e, f,h,j,k
8	N/D	misc.parts		$100		200	400	2	40	discontinued-felt that bags caused plugs		N/A	trash to a compactor	b,c,d,e i,j,k
9	(60)	door latches damper valves	1 1		2 2	N/A	N/A	N/D	N/D	N/A	N/A	N/A	N/D	d,j,k
10	(125)	N/D	N/D	N/D	N/D	52	5-8	12	6	N/D	N/D	INCIN.($10,000)	path-burned, diet -hauled by city	a,b,c,d,g,h
11	(50)	air cylinder push button	6 1	$ 6 $10	2 2	12	3	20	74	24,000	$6	PULP($4,500) HAUL($64/month, 12/month, 32 cu.yd.)	path-burned, diet-hauled	a,d,i
12	(75)	N/D	N/D	N/D	N/D	5	3	2	4	1,600	$60	COMPACT($650/month) HAUL(27 cu.yd., 4 pickups/month)	path-burned, cans/bottles - hauled	b,d
13	(50)	None to Date				N/A	N/A	0	0	N/A	N/A	N/A	N/D	N/D
14	(100)	N/D	N/D	N/D	N/D	25	75-100	10	20	N/D	N/D	COMPACT($380/month)	glass-compacted	a,b,d,e,h,j sanitation & infection control
15	(100)	2 motor bearings		$30	12	4	12-16	3	18	2,250	$35	COMPACT	path-burned	a,b,k

PROBLEMS WITH PNEU. SYSTEM : a. trash and linen ending up in wrong place; b. noise; c. vibration; d. heat in blower room; e. ventilation problem; f. insulation falling off; g. monitoring; h. tube supports pulling out of walls; i. tubes collapsing from metal fatigue; j. lint; k. cycle time forces personnel to wait at charging station.

TABLE F.7

QUESTIONNAIRE ON HOSPITAL SOLID WASTE PULPING SYSTEMS



UNIVERSITY OF MINNESOTA

STUDY OF ECONOMICS OF HOSPITAL SOLID WASTES SYSTEMS: PULPING

Name and address of hospital ______________________

____

Bed capacity __________

1. Make of unit(s) or name of manufacturing company.

2. a. No. of pulping units. __________

b. Capacity of each. __________

3. a. Capacity of water extractor (if more than one, indicate capacity of each and the no. of pulping units connected to each).

b. No. of water extracting screws in each extractor. __________

4. Method of waste collection and transport to pulper(s). (Circle letter of appropriate items)

a. Manual collection and transport
b. Gravity chutes
c. Pneumatic system
d. Other (specify)

5. Method of charging waste into pulper(s). (Circle letter of appropriate items)

a. Manual charging
b. Manual charging onto automatic conveyor
c. Automatic conveyor
d. Other (specify)

6. Diameter and total length of pipe from pulping units to extractor and back to pulping units. If diameters vary, indicate length of pipe for each.

	Pulpers to extractors			Extractors to pulpers		
Diameter						
Length						

7. a. Horsepower of motors per pulping unit (also specify no. of motors of each h.p.)

Horsepower

No. per unit

b. Horsepower of motors per water extractor (also specify no. of each h.p.)

Horsepower

No. per unit

TABLE F.7 (Continued)

Pulping, page 2.

8. a. Total weight of waste generated in hospital per day.

   b. Weight of waste pulped per day.

9. No. of hours of pulper operation per day on: weekdays

   weekends

10. Manhours spent on pulpers for:

    a. Operation per day (includes starting and shutting off units, preparation and injection of sanitizer if used, scheduled observations of pulper operation, etc.) on: weekdays

    weekends

    b. Cleaning per week (includes routine cleaning of units and surrounding areas, and cleaning when unit is temporarily blocked)

    c. Daily removal of waste from junk extractor to container for hauling

11. a. Year of installation.

    b. Indicate if installed in new or existing hospital.

12. Total capital cost. (Please break down costs as follows)

    a. Equipment cost (equipment and accessories delivered to site)

    b. Installation charge, if not included in item 12.a.

    c. Utility hook-up cost, if not included in one of the above two categories. Otherwise indicate which item includes this cost.

    d. Cost of building modification or construction of facilities to house pulper, if not included in one of the above categories. Otherwise indicate which item includes this cost.

13. Maintenance costs.

    a. Replacement of parts (extractor screw, security ring, impeller, motor belts, cutting blades, etc.)

Name of part	No. of parts/unit	Frequency of replacement per year	Cost/part	Manhours needed for replacement

TABLE F.7 (Continued)

Pulping, page 3.

13. b. Lubrication (of motors, bearings, conveyors, etc.)

Part lubricated	Frequency of lubrication per month	Manhours needed for replacement

c. Indicate how accumulated waste is handled while pulper is shut down for repairs.

14. a. Average no. of times per year a pulper will break down for a period of at least 4 hours. ________

b. Total breakdown time per year. ________

15. a. Cost per month for sanitizer, per pulper, if used. ________

b. Capital cost of sanitizer injector. ________

16. Disposal of pulped waste. (Circle letter of appropriate items and answer the questions that follow the item)

a. Discharged to sewer. (What is the cost per gallon?)

b. Incinerated. (What was the cost of the incinerator?)

c. Hauled. (What is the charge per month, no. of pickups per month and the size of the container?)

17. List the types of solid waste which are not pulped, method of disposal and if possible, the cost associated with their disposal.

Waste type ________

Method of disposal ________

Capital cost of equipment if any used. (incinerator, etc.) ________

Time associated with operation of equipment per day ________

18. Problems with pulping system. (Circle letter of appropriate items)

a. odor
b. insects
c. winter freezing
d. noise
e. clogging
f. cleaning
g. injury to personnel
h. other (specify)

TABLE F.8

SUMMARY OF RESPONSES TO PULPING SYSTEM QUESTIONNAIRE
FROM THREE HOSPITALS OF THE 12 HOSPITALS CONTACTED

Hospital	1	2		3		
Bed capacity	182	298		530		
Number of pulpers	1	2		3		
Pulper capacity (lb./hr.)	900	1500	400	1500	1000	2000
Water extractor capacity (lb./hr.)	900	1000	500	one extractor services the 3 units and only 1 unit operates at a time.		
Piping to extractor: Diameter (in.)	3	4	N/D	4	4	4
Length (ft.)	20	150	N/D	292	80	320
Piping from extractor: Diameter (in.)	3	4	N/D	4	4	4
Length (ft.)	30	150	N/D	292	80	320
Horsepower of motors: In the pulper	25	40, 7.5, 1, .75	5, 5	40, 3	23, 3	N/D
In the extractor	5	5, 5	1.5, 1.5	3, 3	3, 3	N/D
Lbs./day of solid waste generated in the hospital.	N/D**	2056		N/D		
Lbs./day of solid waste pulped.	N/D	1500		N/D		
Method of collection and transport of solid waste to the pulper.	manual and gravity chutes	manual and gravity chutes		manual and gravity chutes		
Method of charging of solid waste to the pulper.	manual charging onto conveyor	conveyor from gravity chute and some manual charging		manual charging onto conveyor		
Year of installation*	1968E	1971N		1965E	1967E	1971N
Capital cost breakdown						
Equipment cost	$18,000	$30,926	N/D	$30,000	$20,000	$32,000
Installation cost	$420	N/D	N/D	included in equipment cost		
Utility hook-up cost	$1,180	$3,248	N/D			
Construction cost	$50	N/D	N/D			
Hours of operation on: Weekdays.	10	5	N/D	10	10	not in operation
Weekends.	10	0	N/D	6	6	
Operation manhours on: Weekdays.	3	6	N/D	10	10	not in operation
Weekends.	3	0	N/D	6	6	
Weekly cleaning manhours.	5	10	N/D	16 hrs. for the 3 units		
Daily junk removal manhours.	junk extractor empties directly into container	0.5	N/D	(3 times per week)		
Number of system breakdowns per year exceeding 4 hours	4	none to date		10		
Total breakdown time per year (hr.)	100			40		
Monthly sanitizer cost.	$100	N/D		N/D		
Cost of sanitizer injector.	$80	N/D		N/D		
Disposal of pulped waste	Hauled cost: $128/mth, pickups: 24/mth Container: 6 cu.yd.	Hauled cost: $165/mth, pickups: 21/mth, container: 8 cu.yd.		Hauled cost: $900/mth, pickups: 12/mth, container: 40 cu.yd.		
Treatment and disposal of nonpulpable waste.	metal, wood, bulk plastic are hauled.	glass, cans, bones, wood, metal are hauled.		nonpulpable waste is compacted and hauled.		
How waste is handled when pulping units are shutdown.	incineration	hauling		compaction		
Problems with pulping system.	winter freezing, clogging with plastics.	odor, insects, cleaning.		odor, clogging, cleaning		

* E: existing hospital, N: new hospital.
** N/D: no data

TABLE F.9

ADDITIONAL RESPONSES TO PULPING SYSTEM QUESTIONNAIRE FROM THREE HOSPITALS OF THE 12 HOSPITALS CONTACTED

Hosp.	Name of part	Replacement of parts: Frequency of replacement	Replacement of parts: Cost	Replacement of parts: Manhours needed for replacement	Lubrication of parts: Parts lubricated	Lubrication of parts: Frequency	Lubrication of parts: Manhours needed for lubrication
1	Pulper tank assembly	N/D	$3,521	160	All parts	Monthly	0.5
	Extractor motor	N/D	$164	16			
	Screw and plates	N/D	$71	4			
	Vertical screw	N/D	$461	8			
	Brushings	N/D	$17	4			
	Junk chain	N/D	$241	4			
	Slurry pump	N/D	$920	6			
	Horizontal screw	N/D	$485	16			
	Check valve	N/D	N/D	2			
2	Pulpers are still under warranty.				Motors, conveyors, main drive bearings, junk extractor, water extractor	Monthly	N/D
3	Extractor screw	4.5 yrs.			Cutting head, slurry pump, return pump	2 weeks	6.0
	Extractor screen	4.5 yrs.	$485	18			
	Security ring	4.5 yrs.	$500				
	Impeller	4 mths.	$200-$800				
	Retarder ring	4.5 yrs.	$150	8			
	Cone closer	4.5 yrs.	$73				
	Pumping plate	4.5 yrs.	$74				
	8 junk buckets	2 mths.	$25	3			

APPENDIX G

COMPUTER PROGRAM TO CALCULATE THE VALUES OF THE COST FUNCTIONS FOR THE MANUAL, GRAVITY CHUTE-MANUAL, GRAVITY CHUTE-PNEUMATIC TUBE, INCINERATION, COMPACTION AND PULPING SYSTEMS

A FØRTRAN computer program was written to facilitate the calculation of the values of the cost functions developed in Chapter IV. Within the limitations of the FØRTRAN language, variable notations are the same as those used in Chapter IV. Parameter values depending on hospital characteristics and costs of equipment are read from data cards to permit a particular hospital to insert values applicable to their institution and reflecting changes in equipment costs.

The program given on the following pages was run for a 500 bed hospital using parameter values given in Chapter IV, and the computer output is given at the end of the program.

The program was run at the University of Minnesota Computer Center and makes use of a UCC library function, MEANVAR, which calculates mean and variance.

```
      PROGRAM SYSTEMS(INPUT,OUTPUT)
      DIMENSION EM(25),EG(25),ET(25),COST(10),MOTOR(10),AREA(10),COST1(1
     C0),COST2(10),PS(5),EB(25),EC(25),EP(25)
      REAL I,N1,N2,NI,N,LI,NIJ,M,NOPT,NO,L,K,MOTOR
C
C
C     MANUAL SYSTEM
C
      READ  1,AB,A11,A12,B,BLDG,C,C1,C2,C3,C4,E,FI,FW,I,IF1,IF2,TE,TO,TR
     C,TS,TVI,TW,WC,Y
    1 FORMAT(8F10.2,/,6F10.2,2I10,/,3F10.2,F10.3,4F10.2)
C
C     PARAMETER VALUES
C     AB=750     A11=4      A12=25     B=500      BLDG=1     C=3        C1=20
C     C2=250     C3=2       C4=.05     E= 2.5     FI=2       FW=50      I=.1
C     IF1=5      IF2=16     TE=1       TO=.62     TR=.12     TS=.006    TVI=.09
C     TW=1.37    WC=100     Y=10
C
      PRINT 5
    5 FORMAT(1H1,//,5X,13HMANUAL SYSTEM)
      PRINT 10,B
   10 FORMAT(//,5X,4HBEDS,/,5X,F4.0)
      PRINT 15
   15 FORMAT(/,33X,12HANNUAL EQUIV,3X,11HANNUAL OPER,/,2X,6HFLOORS,3X,8H
     CSECTIONS,3X,8HTIME(HR),3X,12HCAPITAL COST,3X,12H& MAINT COST,3X,17
     CHTOTAL ANNUAL COST)
      INDX=0
      F=IF1-1
      DO 61 J=IF1,IF2
      INDX=INDX+1
      F=F+1.0
      BI=B/F
      WI=B.5*.8*BI
      INTLI=WI/(FI*WC)
      REALLI=WI/(FI*WC)
      LI=INTLI
      DIFF=LI-REALLI
      IF(DIFF.GE.0.0) GO TO 20
      LI=LI+1.0
   20 NI=WI/(15.0*FI)
      AI=AB*BI
      FL=AI/FW
      IF(BLDG.EQ.2.0) GO TO 22
      PI=2.0*FW+2.0*FL
      GO TO 23
   22 AIJ=AI/LI
      NIJ=NI/LI
      D=(AIJ*NIJ)**0.5
      PI=LI*D
   23 IF(LI.GT.2.0) GO TO 25
      DI=0.0
      GO TO 35
   25 IE=LI/2.0
      O=LI/2.0
      E=IE
      IF(E.EQ.O) GO TO 30
      DI=(((LI-1.0)**2)*FL)/(4.0*LI)
      GO TO 35
   30 DI=((LI-2.0)*FL)/4.0
   35 D=FL/2.0
      HI=PI+DI+2.0*D*LI
      TH=F*FI*HI*TS
      TL=F*FI*NI*TE
      TV=F*FI*LI*2.0*(((F-1.0)/2.0)*TVI+TW+TO)
      TU=F*FI*NI*TR
      T=(TH+TL+TV+TU)*1.17/60.0
      EM3=T*365.0*C
      EM4=F*FI*NI*365.0*C4
      V=0.0
      IF(F.LE.5.0) GO TO 40
      V=0.25*(F-5.0)
   40 TV1=F*FI*LI*(F-1.0)*TVI
      EM5=(E+V)*TV1*365.0/60.0
      EM2=EM3+EM4+EM5
      IF(T.GT.8.0) GO TO 45
      N2=2.0
      GO TO 55
   45 IF(T.GT.16.0) GO TO 50
      N2=3.0
      GO TO 55
   50 N2=4.0
   55 N1=NI*F
      A1=A11*N1+A12*N2
      EM1=(N1*C1+N2*C2)*I*(I+1.0)**Y/((I+1.0)**Y-1.0)+A1*C3
      EM(INDX)=EM1+EM2
      PRINT 60,F,LI,T,EM1,EM2,EM(INDX)
   60 FORMAT(/,F6.0,6X,F4.0,7X,F5.1,6X,F10.2,5X,F10.2,8X,F10.2)
   61 CONTINUE
      CALL MEANVAR(AVE,VAR,EM,INDX)
      SD=VAR**0.5
      PRINT 65,AVE,SD
   65 FORMAT(/,63X,4HMEAN,F10.2,/,49X,18HSTANDARD DEVIATION,F10.2)
   66 CONTINUE
C
C
C     GRAVITY CHUTE - MANUAL SYSTEM
C
      PRINT 105
  105 FORMAT(1H1,//,5X,29HGRAVITY CHUTE - MANUAL SYSTEM)
      PRINT 10,B
      PRINT 115
  115 FORMAT(/,31X,12HEQUIV ANNUAL,3X 11HANNUAL OPER,/,2X,6HFLOORS,3X,6H
     CCHUTES,3X,8HTIME(HR),3X,12HCAPITAL COST,3X,12H& MAINT COST,3X,17HT
     COTAL ANNUAL COST)
      READ 116,AB,A10,A11,A12,C,C1,C2,C3,C4,C6,C7,FW,I,TN,TP,TR,TS,WC,WT
     C,Y,Z
  116 FORMAT(8F10.2,/,6F10.2,F10.3,F10.2,/,F10.3,4F10.2)
C
C     PARAMETER VALUES
C     AB=750    A10=4     A11=50    A12=80    C=3       C1=20     C2=250
C     C3=2      C4=.06    C6=1100   C7=500    FW=50     I=.1      TN=1.26
C     TP=.005   TR=.12    TS=.005   WC=120    WT=18     Y=10      Z=50
C
      W=8.5*.9*8
      TL=W/WT*TN
      TU=W/WT*TR
      EG4=W/WT*C4*365.0
      A=AB*B
      INDX=0
      F=IF1-1
      DO 126 J=IF1,IF2
      INDX=INDX+1
      F=F+1.0
      DA=A/(F*FW*2.0)
      NOPT=((.5*W/WT*.76*A**0.5*TP+1.17*365.0/60.0*C)/((C6+C7/F)*I*(1.0+
     CI)**Z/((1.0+I)**Z-1.0)+C3*(A11+A12/F)+C*365.0/(2.0*F)))**0.667
      INTM=NOPT/F
      IF(INTM.NE.0) GO TO 120
      INTM=1
  120 M=INTM
      N=M*(F-1.0)
      NO=M*F
      N1=B/20.0
      N2=M+1.0
      A1=A10*N1+A11*N+A12*M
      EG1=(N1*C1+N2*C2)*I*(1.0+I)**Y/((1.0+I)**Y-1.0)+(N*C6+M*C7)*I*(1.0
     C+I)**Z/((1.0+I)**Z-1.0)+A1*C3
      TH=W/WT*0.76*(A/NO)**0.5*TP+W/WC*2.0*DA*TS
      TC=M*30.0
      T=(TH+TL+TU+TC)*1.17/60.0
      EG3=T*365.0*C
      EG2=EG3+EG4
      EG(INDX)=EG1+EG2
      PRINT 125,F,M,T,EG1,EG2,EG(INDX)
  125 FORMAT(/,F6.0,5X,F4.0,5X,F6.1,6X,F10.2,5X,F10.2,8X,F10.2)
  126 CONTINUE
      CALL MEANVAR(AVE,VAR,EG,INDX)
      SD=VAR**0.5
      PRINT 130,AVE,SD
  130 FORMAT(/,61X,4HMEAN,F10.2,/,47X,18HSTANDARD DEVIATION,F10.2)
  131 CONTINUE
C
C
C     GRAVITY CHUTE - PNEUMATIC TUBE SYSTEM
C
      PRINT 205
  205 FORMAT(1H1,//,5X,37HGRAVITY CHUTE - PNEUMATIC TUBE SYSTEM)
      PRINT 10,B
      PRINT 215
  215 FORMAT(/,20X,9HLENGTH OF,14X,12HEQUIV ANNUAL,3X,11HANNUAL OPER,/,2
     CX,6HFLOORS,3X,6HCHUTES,3X,9HPNEU TUBE,3X,8HTIME(HR),3X,12HCAPITAL
     CCOST,3X,12H  MAINT COST,3X,17HTOTAL ANNUAL COST)
      READ 215,AB,ALFA,A10,A11,A12,A13,BETA,C,CC,C1,C31,C32,C4,C5,C6,C7,
     CC8,C11,FW,HP,I,S,TN,TP,WT,X,Y,Z
  216 FORMAT(8F10.2,/,8F10.2,/,7F10.2,F10.3,/,4F10.2)
C
C     PARAMETER VALUES
C     AB=750      ALFA=30    A10=4      A11=80     A12=48     A13=2000   BETA=100
C     C=3         CC=9000    C1=20      C31=2      C32=2      C4=.06     C5=.02
C     C6=1100     C7=7200    C8=50      C11=30000  FW=50      HP=50      I=.1
C     S=50        TN=1.26    TP=.005    WT=18      X=25       Y=10       Z=50
C
      W=8.5*.8*B
      TL=W/WT*TN
      ET4=W/WT*C4*365.0
      A=AB*B
      INDX=0
      F=IF1-1
      DO 231 J=IF1,IF2
      INDX=INDX+1
      F=F+1.0
      DA=A/(F*FW*2.0)
      NOPT=((.5*W/WT*.76*A**0.5*TP*1.17*365.0/60.0*C)/(C6*I*(1.0+I)**Z/(
     C(1.0+I)**Z-1.0)+C7/F*I*(1.0+I)**X/((1.0+I)**X-1.0)+C31*(A11+A12/F)
     C+C*365.0/(2.0*F)))**0.667
      INTM=NOPT/F
      IF(INTM.NE.0) GO TO 220
      INTM=1
  220 M=INTM
      N=M*(F-1.0)
      N0=M*F
      N1=B/20.0
      A1=A10*N1+A11*N+A12*M
      A2=A13
      C9=CC
      K=HP*0.746
      L=M/(M+1.0)*DA*2.0
      IF(L.LE.200.0) GO TO 225
      C9=C9*2.5*(L-200.0)
      K=K+(0.04*(L-200.0))*0.746
  225 C10=9.0*L+1800.0*M
      ET1=N1*C1*I*(1.0+I)**Y/((1.0+I)**Y-1.0)+(M*C7+L*C8+C9+C10+C11)*I*(
     C1.0+I)**X/((1.0+I)**X-1.0)+(A1*C31+A2*C32)+N*C6*I*(1.0+I)**Z/((1.0
     C+I)**Z-1.0)
      TH=W/WT*0.76*(A/N0)**0.5*TP
      TC=M*30.0
      T=(TH+TL+TC)*1.17/60.0
      ET3=T*365.0*C
      PP=(L/S+ALFA)*(W/BETA)*(.746*K/3600.0)
      ET5=PP*365.0*C5
      ET2=ET3+ET4+ET5
      ET(INDX)=ET1*1.05+ET2
      PRINT 230,F,M,L,T,ET1,ET2,ET(INDX)
  230 FORMAT(/,F6.0,5X,F4.0,5X,F8.1,4X,F6.1,6X,F10.2,5X,F10.2,8X,F10.2)
  231 CONTINUE
      CALL MEANVAR(AVE,VAR,ET,INDX)
      SD=VAR**0.5
      PRINT 235,AVE,SD
  235 FORMAT(/,73X,4HMEAN,F10.2,/,59X,18HSTANDARD DEVIATION,F10.2)
  236 CONTINUE
C
C
C     INCINERATION SYSTEM
C
      PRINT 300
  300 FORMAT(1H1,//,5X,19HINCINERATION SYSTEM)
      PRINT 10,B
      PRINT 310
  310 FORMAT(/,25X,12HANNUAL EQUIV,3X,11HANNUAL OPER,/,2X,20HINCINERATOR
     C CAPACITY,3X,12HCAPITAL COST,3X,12H+ MAINT COST,3X,17HTOTAL ANNUAL
     C COST)
      READ 311,A,ALFA,A1,B1,C,C2,C3,H,I,X
  311 FORMAT(5F10.2,F10.3,2F10.2,/,2F10.2)
C
C     PARAMETER VALUES
C     A=62        ALFA=.8    A1=250     B1=.87     C=3         C2=.002    C3=2
C     H=15        I=.1       X=10
C
      INDX=0
      W=8.5*.8*8
  315 IF(H-2.0) 351,351,325
  325 Q=W/H
      INDX=INDX+1
      C1=A*Q**B1
      EB1=C1*I*(1.0+I)**X/((1.0+I)**X-1.0)+A1*C3
      EB3=365.0*1.25*W/(ALFA*Q)*C
      EB4=365.0*W/ALFA*C2
      EB5=0.05*C1
      EB2=EB3+EB4+EB5
      EB(INDX)=EB1+EB2
      PRINT 350,Q,EB1,EB2,EB(INDX)
  350 FORMAT(/,8X,F8.2,9X,F10.2,5X,F10.2,10X,F10.2)
      H=H-2.0
      GO TO 315
  351 CALL MEANVAR(AVE,VAR,EB,INDX)
      SD=VAR**0.5
      PRINT 355,AVE,SD
  355 FORMAT(/,56X,4HMEAN,F10.2,/,42X,18HSTANDARD DEVIATION,F10.2)
  356 CONTINUE
C
C
C     COMPACTION SYSTEM
C
      PRINT 400
  400 FORMAT(1H1,//,5X,17HCOMPACTION SYSTEM)
      PRINT 10,B
      PRINT 410
  410 FORMAT(/,23X,12HANNUAL EQUIV,3X,11HANNUAL OPER,/,2X,18HCONTAINER C
     CAPACITY,3X,12HCAPITAL COST,3X,12H+ MAINT COST,3X,17HTOTAL ANNUAL C
     COST)
      READ 411,A,(AREA(I),I=1,3),A12,B1,C,(COST(I),I=1,3),C31,C32,C41,C5
     C,I,(MOTOR(I),I=1,3),R,TM,WC,Y
  411 FORMAT(9F10.2,/,8F10.2,/,5F10.2)
C
C     PARAMETER VALUES
C     A=340       AREA(1)=250  AREA(2)=350  AREA(3)=400   A12=400   B1=875
C     C=3         COST(1)=4300 COST(2)=5000 COST(3)=6000  C31=2     C32=2
C     C41=.02     I=.1        MOTOR(1)=7.5 MOTOR(2)=10 MOTOR(3)=15  R=40
C     TM=45       WC=100      Y=10
C
      INDX=0
      W=8.5*.8*8
  415 IF(R) 451,451,425
  425 IF(R-20.0) 430,435,440
  430 J=1
      GO TO 445
  435 J=2
      GO TO 445
  440 J=3
  445 INDX=INDX+1
```

```
      C1=A+B1*R
      C2=COST(J)
      A11=AREA(J)
      EC1=(C1+C2)*I*(1.0+I)**Y/((1.0+I)**Y-1.0)+(A11*C31+A12*C32)
      EC3=(365.0*W)/(320.0*R)*(C41+0.9*R)
      EC4=365.0*(1.0+W/WC)*(TM/3600.0)*C
      K=MOTOR(J)
      EC5=365.0*(0.746*K)*(W/WC)*(TM/3600.0)*C5
      EC6=365.0*W/(320.0*R)
      EC2=EC3+EC4+EC5+EC6
      EC(INDX)=EC1+EC2
      PRINT 450,R,EC1,EC2,EC(INDX)
  450 FORMAT(/,10X,F4.0,9X,F10.2,5X,F10.2,10X,F10.2)
      R=R-10.0
      GO TO 415
  451 CALL MEANVAR(AVE,VAR,EC,INDX)
      SD=VAR**0.5
      PRINT 455,AVE,SD
  455 FORMAT(/,54X,4HMEAN,F10.2,/,40X,18HSTANDARD DEVIATION,F10.2)
  456 CONTINUE
C
C
C     PULPING SYSTEM
C
      PRINT 500
  500 FORMAT(1H1,//,5X,14HPULPING SYSTEM)
      PRINT 10,H
      PRINT 510
  510 FORMAT(/,16X,12HANNUAL EQUIV,3X,11HANNUAL OPER,,4X,12HANNUAL HAUL-,
     C/,2X,11HPULPER SIZE,3X,12HCAPITAL COST,3X,12H& MAINT COST,3X,8HHING
     C COST,7X,17HTOTAL ANNUAL COST)
      READ 511,A1,A2,C,CG,CP,(COST1(I),I=1,2),C1P,(COST2(I),I=1,2),C2P,C
     C31,C32,C3P,C41,C5,EP5,EP7,H,HK,I,L,(PS(I),I=1,2),R,T1,T2,Y
  511 FORMAT(8F10.2,/,8F10.2,/,8F10.2,/,4F10.2)
C
C     PARAMETER VALUES
C     A1=500     A2=400      C=3          CG=.06     CP=6        COST1(1)=19000
C     COST1(2)=21000         C1P=1000     COST2(1)=6000          COST2(2)=9000
C     C2P=500    C31=2       C32=2        C3P=7      C41=16      C5=.02      EP5=200
C     EP7=2000   H=5         HK=75        I=.1       L=200       PS(1)=7000 PS(2)=1500
C     R=10       T1=343      T2=548        Y=10
C
      INDX=0
      W=8.5*.8*8
      DO 551 J=1,2
      INDX=INDX+1
      C1=COST1(J)
      C2=COST2(J)
      EP1=(C1+C2+C1P+C2P+L*C3P)*I*(1.0+I)**Y/((1.0+I)**Y-1.0)+(A1*C31+A2
     C*C32)
      EP3=T1*CP+T2*C
      EP4=365.0*(0.746*HK*H)*C5
      EP6=365.0*W/100.0*CG
      EP2=EP3+EP4+EP5+EP6+EP7
      EPH=365.0*W/(300.0*R)*(C41+0.9*R)
      EP(INDX)=EP1+EP2+EPH
      PRINT 550,PS(J),EP1,EP2,EPH,EP(INDX)
  550 FORMAT(/,5X,F6.0,5X,F10.2,5X,F10.2,5X,F10.2,10X,F10.2)
  551 CALL MEANVAR(AVE,VAR,EP,INDX)
      SD=VAR**0.5
      PRINT 555,AVE,SD
  555 FORMAT(/,72X,4HMEAN,F10.2,/,58X,18HSTANDARD DEVIATION,F10.2)
  556 CONTINUE
      END
```

```
MANUAL SYSTEM

BEDS
 500

FLOORS   SECTIONS   TIME(HR)   ANNUAL EQUIV    ANNUAL OPER
                               CAPITAL COST    + MAINT COST    TOTAL ANNUAL COST
   5         4        19.9        1638.30        26886.01          28524.31
   6         3        17.5        1638.30        24316.11          25954.41
   7         3        18.2        1638.30        25073.76          26712.06
   8         3        18.9        1638.30        25885.68          27523.98
   9         2        15.5        1547.62        22230.40          23778.01
  10         2        15.9        1547.62        22862.43          24410.05
  11         2        16.4        1638.30        23540.50          25178.80
  12         2        16.9        1638.30        24267.89          25906.19
  13         2        17.4        1638.30        25047.88          26686.18
  14         2        17.9        1638.30        25883.76          27522.06
  15         2        18.5        1638.30        26778.81          28417.11
  16         2        19.0        1638.30        27736.32          29374.62

                                                         MEAN  26665.65
                                           STANDARD DEVIATION   1707.02


GRAVITY CHUTE - MANUAL SYSTEM

BEDS
 500

FLOORS   CHUTES   TIME(HR)   EQUIV ANNUAL    ANNUAL OPER
                             CAPITAL COST    + MAINT COST    TOTAL ANNUAL COST
   5        1       13.6        1416.95        19077.83          20494.78
   6        1       12.6        1627.90        17955.89          19583.79
   7        1       11.9        1838.85        17131.49          18970.34
   8        1       11.3        2049.79        16497.26          18547.05
   9        1       10.8        2260.74        15992.38          18253.12
  10        1       10.5        2471.69        15579.76          18051.45
  11        1       10.1        2682.63        15235.40          17918.02
  12        1        9.9        2893.57        14943.05          17836.63
  13        1        9.6        3104.52        14691.33          17795.85
  14        1        9.4        3315.46        14471.99          17787.45
  15        1        9.3        3526.41        14278.90          17805.31
  16        1        9.1        3737.35        14107.42          17844.78

                                                         MEAN  18407.38
                                           STANDARD DEVIATION    865.01
```

```
GRAVITY CHUTE - PNEUMATIC TUBE SYSTEM

BEDS
 500

                     LENGTH OF                 EQUIV ANNUAL   ANNUAL OPER
FLOORS    CHUTES     PNEU TUBE    TIME(HR)     CAPITAL COST   + MAINT COST    TOTAL ANNUAL COST
   5         1          750.0        9.1         15775.64       14180.75            30745.17
   6         1          625.0        8.7         15199.67       13799.98            29759.63
   7         1          535.7        8.5         14865.67       13505.58            29114.54
   8         1          468.8        8.3         14682.91       13269.17            28686.22
   9         1          416.7        8.1         14600.57       13073.90            28404.92
  10         1          375.0        7.9         14589.61       12909.08            28229.18
  11         1          340.9        7.8         14629.58       12767.55            28129.61
  12         1          312.5        7.7         14708.04       12644.28            28087.73
  13         1          288.5        7.6         14816.12       12535.66            28092.59
  14         1          267.9        7.5         14947.46       12439.01            28133.85
  15         1          250.0        7.4         15097.42       12352.28            28204.57
  16         1          234.4        7.4         15252.50       12273.37            28299.50

                                                                          MEAN  28657.13
                                                            STANDARD DEVIATION    929.12



    INCINERATION SYSTEM

    BEDS
     500

                           ANNUAL EQUIV    ANNUAL OPER
    INCINERATOR CAPACITY   CAPITAL COST    + MAINT COST    TOTAL ANNUAL COST
           212.50             1568.32        30805.72           32374.04
           242.86             1699.93        27424.28           29124.21
           283.33             1872.14        24055.31           25927.45
           340.00             2108.00        20705.90           22813.90
           425.00             2452.53        17389.87           19842.41
           566.67             3007.81        14138.60           17146.41
           850.00             4068.58        11042.62           15111.19

                                                             MEAN  23191.37
                                               STANDARD DEVIATION   6327.12
     COMPACTION SYSTEM

     BEDS
      500

                          ANNUAL EQUIV     ANNUAL OPER
 CONTAINER CAPACITY       CAPITAL COST     + MAINT COST    TOTAL ANNUAL COST

              40            8327.89          5173.23               13501.13

              30            6903.87          5722.63               12626.51

              20            5217.10          6809.86               12026.97

              10            3479.16         10100.48               13579.64

                                                            MEAN   12933.56
                                              STANDARD DEVIATION     742.91
```

```
  PULPING SYSTEM

  BEDS
   500

                ANNUAL EQUIV    ANNUAL OPER     ANNUAL HAUL-
 PULPER SIZE    CAPITAL COST    + MAINT COST    ING COST         TOTAL ANNUAL COST

       700         6340.60         8688.77        10341.67             25371.04

      1500         7154.32         8688.77        10341.67             26184.77

                                                                        MEAN  25777.90
                                                          STANDARD DEVIATION    575.39
```

APPENDIX H

OPERATION GUIDELINES

During the two year duration of this study, extensive information has been accumulated on the operation of hospital solid waste handling systems. Sources include the literature and data supplied by manufacturers, however the most illustrative information has been obtained from observation of hospital solid waste handling systems in operation.

Certain minimum operation standards, derived from this information, have been expanded into a set of operation guidelines for seven possible hospital solid waste handling systems. The guidelines are designed to present an overall view of the total operation of a system with particular attention to aspects of the operation which are not detailed in brochures from manufacturers, potential problems and possible preventive measures, and maintenance requirements and suggested preventive maintenance.

It must be stated that the guidelines are *suggested* measures to provide for the safe and efficient operation of the different systems, and that the operation and maintenance problems discussed represent *potential* problems that could occur.

The primary reasons for developing the guidelines were to provide hospital personnel with a preview of the total operation of a solid waste handling system prior to purchase and installation, and to assist them in developing guidelines for the operation of their particular system.

Alain G. DuChene

Alain G. DuChene

OPERATION GUIDELINES

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OPERATION GUIDELINES: MANUAL SYSTEM

I. Containers

  A. Location

    1. Waste baskets should be located throughout the hospital at or near points of waste generation.

    2. If waste, such as noncombustibles, needles and syringes or pathological wastes, is to be separated from other wastes, containers should be located near the points of generation of the waste to encourage personnel to deposit waste in the appropriate containers.

      a. Containers for special waste should be well marked and be of uniform size and shape to be easily identifiable.

    3. If waste collected from one or more floors is to be temporarily stored within the hospital and later moved to some central processing area, containers or carts into which the waste is placed should be located in a separate room such as a utility room.

      a. Bags of waste stuffed in a container or cart sitting in the corridor is unacceptable for patients, visitors or hospital personnel. Temporarily storing wastes in a room such as a properly ventilated utility room will help contain odors and diminish the chances of cross contamination.

      b. The room should be constructed of fire resistant materials, properly ventilated and cleaned at least daily.

  B. Type and size of container

    1. Type

a. It is best to have containers constructed of materials that are noncombustible, corrosion resistant, leakproof and easy to clean.

b. Prevention of excessive noise that could be produced as containers are emptied should be considered when choosing between containers of different materials.

c. Containers for temporary storage of possibly hazardous waste, such as needles and syringes or pathological waste, must have covers for the protection of patients and personnel.

d. Containers which are located in corridors, lounges, cafeterias or other areas of heavy patient, visitor and employee traffic should have covers for esthetic reasons. Containers with self-closing covers such as the swing-top or flip-top variety would be best for these areas.

2. Size

a. Containers should be sized so that when full they are not too heavy to be lifted and dumped into the cart. If liners are used, containers should be sized so that the filled liner can be easily lifted out of the container into the cart.

b. Standardization of waste container size and shape throughout the hospital is recommended. By not limiting the containers to a few basic sizes and shapes, the hospital would be forced to stock many different size and shape liners to fit the containers. Because the cost per liner usually decreases if larger quantities are purchased, the hospital should realize some cost savings through standardization.

C. Use of liners

1. It is desirable to use liners for all containers.

    a. Liners help keep the containers clean and protect metal containers from corrosion. Using liners extends the life of the container by reducing the wear and tear on the containers during the process of emptying.

    b. Liners help contain odors and reduce aerosol spread during transport.

2. Liners should be made of materials that are leakproof and strong enough not to rupture while in the container or when being removed.

    a. Strength of liner required will depend on the size of the container and the density of material to be placed in the liner.

    b. Ideally the liners should not rupture during the process of transport and storage within the hospital. However this is not always practical.

        - For example it would be difficult (expensive) to obtain a liner which would stay intact after it had been dropped down a vertical chute, particularly after several other bags of waste had landed on top of it.

3. If liners are used, they should be large enough to overlap the top of the container so that they can be closed

easily without having to compact the waste by hand, thus reducing the possibility of injury from such things as broken glass or an exposed needle.

4. Liners should be color coded to indicate what type of waste is inside. This will help collection personnel identify those wastes, such as pathological wastes, which require special handling and disposal.

II. Collection and transport

   A. Type of cart for collection and/or transport

      1. The cart should be constructed of materials that can withstand abuse and have smooth surfaces for easy cleaning. The cart also should be leakproof and have rubber bumpers or other features to reduce noise as the cart travels through the hospital.

      2. It is recommended that the carts have covers for esthetic reasons, to prevent collection personnel from overloading the cart, and to prevent spillage. Carts used to transport potentially hazardous wastes such as pathological wastes should have covers to protect patients and personnel.

   B. Size of cart for collection and/or transport

      1. The cart should be approximately one cubic yard in capacity so that it will fit through doorways, be easily maneuvered around corners, and allow the person pushing the cart to see over it. These restrictions do not necessarily apply to an automated or monorail cart system.

      2. Smaller carts such as the frame type with a plastic,

paper or cloth liner attached are adequate for situations where waste is collected on a floor and vertically transported by some other means such as a gravity chute.

C. Methods of collection and transport

1. Collection

In most hospitals, waste is collected from waste baskets by maids as they make their cleaning rounds. Some hospitals may designate certain personnel whose only function is the collection of waste. Staff from certain areas of the hospital, such as surgery, the laboratory, or the kitchen, may collect and transport the waste from those areas.

a. Liners removed from containers should be sealed before they are placed in the collection cart or moved to another location.

b. Frame type carts used to collect waste from rooms are lined with a paper, plastic or cloth lining, which when full is dropped down a chute, stored on the floor to be picked up later or moved directly to a central collection point. Although most of the waste is bagged, it is recommended that plastic or moisture proof paper be used in the carts instead of a cloth material. The paper or plastic liners can be discarded, but a cloth liner will need frequent washing.

c. If a large cart (approximately one cubic yard) is used to collect waste from rooms on one or more floors, it would be impractical to line it with a paper or plastic liner.

- Since these carts travel in patient areas, they should be cleaned whenever they are unloaded.

2. Transport

Once the waste has been collected on the floors it can be dropped down a gravity or pneumatic chute, stored on the floor until picked up later or transported directly to some central collection point.

a. Chutes (gravity or pneumatic)

Chutes can be connected directly to processing equipment, such as a compactor, pulper or incinerator. In many cases gravity chutes are used to move the waste vertically from where it is collected, after which it is moved manually to some central point.

- If the bags of waste are manually handled at the bottom of the chute there is the possibility of injury from protruding sharp objects.

b. Automated or monorail cart systems

- Volume and weight limitations restrict the use of these systems for transporting large quantities of waste.

c. Manual transport from the floors

- A specific route should be set up to economize on the time spent doing this task.
- As large a cart as possible should be used or more

frequent collections should be made and/or the number of pickup points during one route should be limited so that collection personnel do not have to manually compact bags of waste into the cart. Packing could tear the bags of waste and also presents the possibility of physical injury by protruding sharp objects.

- Passenger elevators should not be used to transport waste.

D. Special waste restrictions

Depending on the method of transport and disposal, or the nature of the hospital waste, separate handling of the waste may be necessary. Separation of waste should be performed at or near the points of waste generation. This can be handled in two ways. First, by segregation of waste according to departments. For example, all waste from Purchasing Department, the Administrative Department, the Record Keeping Department and possibly the kitchen could be considered as non-infectious waste, and the remainder of the hospital waste could be considered infectious. The second way is to segregate waste at the point of generation. This is usually the approach taken in hospitals. One cannot make any hard and fast rules as to separation, because it depends upon the method of transport and disposal. However, for the cart system there are some factors that are usually considered in regard to transport of the waste in the hospital.

1. Needles and syringes are usually placed in one type of container to avoid physical injury to collection personnel.

    a. They are sometimes broken, especially if they are hauled away, so that they cannot be reused. If they are incinerated on-site, it is not necessary to break the unit.

2. Infectious waste and pathological waste are often collected separately from other waste for esthetic reasons and to prevent the spread of micro-organisms within the facility. However the final mode of disposal of these wastes may also be different. Many hospitals, by law, must incinerate pathological waste, but they may have the infectious waste hauled away.
    a. These wastes should be placed in an impervious plastic or paper bag, possibly double bagged, and closed securely. Bags might be marked or color coded to identify the type of waste.
    b. These wastes should not be dropped down a chute.
    c. Even if all waste is incinerated, it is recommended that these wastes be collected and transported separately from other waste.
        - To insure proper handling, some hospitals have personnel from the services where the waste is generated, transport these wastes to the incinerator and also charge them into the incinerator.
3. Toxic and hazardous waste should be handled separately. This category includes toxic and flammable chemicals, caustic chemicals, explosive chemicals, radioactive materials, chemicals, and compressed gas cylinders.

a. Special types of transportation equipment and storage facilities are needed for these categories of waste in medical care facilities. Volumes 1, 2, and 3 of the National Fire Protection Association's National Fire Codes are the recommended guides for determining the necessary precautions in the handling of toxic and hazardous waste.

b. It is recommended that competent personnel, possibly technicians from the areas where these wastes are generated, handle the collection and transport of these wastes within the hospital.

c. NFPA codes suggest that hazardous materials should be disposed of away from the hospital by a commercial disposal specialist, or at a safe distance from the hospital building, by competent personnel using procedures established in coordination with local fire and pollution control authorities.[3]

4. Glass containers, cans and/or other noncombustibles are often segregated into a separate container at the point of generation.

   a. This may be done for the protection of housekeeping personnel so that they know what they are handling and do not receive cuts or abrasions from broken pieces of glass or needles protruding out the sides of bags.

   b. This may be done to segregate waste for transport and/or disposal, in particular for pneumatic systems, incinerators or pulpers where problems occur if certain wastes are charged into these systems.

5. Kitchen waste

   a. The garbage generated in the kitchen is usually treated in garbage disposals, although some hospitals still sell their garbage to hog farms.

   b. Other waste from the kitchen such as cans, bottles, bones, packaging and disposable tableware are often collected and transported by kitchen personnel after each meal.

   c. Containers or carts used to transport this waste should be cleaned whenever they are emptied to prevent odors.

F. Frequency of collection from different areas of the hospital.

1. Waste from most areas of the hospital can be collected once per day although twice a day collection is preferable for esthetic reasons.

2. Waste from patient rooms should be collected twice per day mainly for esthetic reasons.

3. Infectious waste should be containerized on site and should be collected at least once per day. It should not be dropped down a chute, but delivered directly to the on-site storage facility or hospital incinerator.

4. Waste from surgery, obstetrical and autopsy sites should be collected after each procedure and be removed from the particular room.

   a. In some hospitals, pathological waste is transported by technicians directly to the hospital incinerator or other on-site treatment or storage facility. It can be stored in the area if it is placed in closed containers and refrigerated or collected at least twice daily.

5. Laboratory waste should be collected once per day.
    a. There should be pretreatment by autoclaving of culture plates and other waste containing viable organisms.

F. Time for collection

The best time for collection of the various types of waste would depend partially on the type of collection/transport/disposal system. For example, with a pneumatic system collection can be more or less continuous.

1. With a cart type system, it is best to have collection from the patient areas at the times when other types of activity, such as caring for patients and serving meals, are at a low level. Times of high patient care activity could be used for collection of waste from areas such as the laboratory and administrative offices.
2. Because of the noise factor, waste should not be collected from patient areas in the evening hours. However, it may be best to collect waste form the surgical areas in the evening hours prior to cleanup for the next day.

III. Prevention of problems arising from improper handling of waste (injuries, cross infection, odors, unsightliness)

A. An educational campaign is essential to assure that the people who generate the waste are aware of the possible dangers to patients or other personnel if certain waste such as needles or pathological waste, is indiscriminately thrown away. They should be encouraged to deposit waste of a particularly hazardous nature in specified containers which should be located at or near the points of waste generation. The personnel who collect and transport the waste should be made aware of the possible dangers in handling hospital waste and that hazardous waste can sometimes get mixed in with other wastes.

1. Collection personnel should be encouraged to handle wastes in a manner that would diminish the chances of injury.
    - a. They should not compact waste into the containers with their hands.
    - b. They should handle liners filled with waste from the top, and avoid placing a hand under the liner.
    - c. They should not force bags into the transport cart, but make another trip.

B. The department supervisor responsible for waste handling should frequently observe the collection and transport of waste so that adjustments can be made before problems arise.

1. The amount of waste generated in an area may require the addition of several waste containers.
2. Collection routes may have to be changed if carts are being overloaded on present routes.

IV. Maintenance of containers and carts

A. Containers

1. Containers should be washed after each use or when there is any visible soil on the surfaces. If liners are used, the frequency of washing can be decreased.

2. Containers should be checked periodically for damage such as dents, chipped paint, or holes which could permit leakage. If the container cannot be properly repaired, it should be discarded.

B. Carts

1. Carts should be washed so that all visible soil is removed. This should be done at least once per day or after any load where visible soil remains on the cart.
2. Carts should be kept in good repair and wheels should be lubricated periodically for noise prevention.

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OPERATION GUIDELINES: GRAVITY CHUTE SYSTEM

I. Charging stations

  A. Location

    1. Many building codes prohibit the location of charging stations in corridors primarily to prevent backdrafts of smoke or bacterial aerosols into the hospital. Even if backdrafts are controlled by maintaining negative pressure in the chutes, there are esthetic reasons why charging stations should not be located in corridors.

    2. The National Fire Protection Association codes state that charging stations should be located in a separate room or compartment such as a utility room.[2]

      a. Floors, walls and ceilings should be constructed of fire resistant materials having a rating of not less than 1 hour, and the room should also have approved fire doors.[2]

      b. Some consideration should be given to the size of the room because if the hospital decides to separate certain wastes, such as glass or needles and syringes, it may be necessary to locate several waste receptacles in the room to collect the wastes. Collection personnel are more likely to separate the wastes instead of throwing everything down the chute, if the containers are in the same room.

      c. Access to the room should be limited to authorized personnel.

  B. Type of charging station

    1. Doors

a. The doors should be self-closing, self-latching and the dimensions of the door should not be larger than the dimensions of the chute.

b. Doors should be interlocked so that only one door can be opened at a time. This would prevent backdrafts produced by the piston effect of a bag of waste passing an open door as well as preventing a bag charged from an upper floor striking a bag being charged from below.

c. Locks can be provided on the charging doors to limit chute access to only authorized personnel. In an existing hospital, with chute charging stations in the corridors, locks should be installed on the charging doors. If the charging station is in a separate room, the locks are not necessary.

d. Three types of doors are available.

  - Bottom hinged doors are usually recommended because they provide a receptacle to pour waste into and keep waste from falling on the floor. They can be foot operated so that collection personnel can use both hands to charge wastes.
  - Side hinged doors are also appropriate if wastes are bagged because the bags eliminate the problem of spillage. The side hinged door provides a larger opening than a similar sized bottom hinged door. A square, side hinged door is preferable to a round, side hinged door because there can only be one small hinge on the round door due to its shape.

      - Top hinged, push in type doors are not recommended because the door is easily soiled and there is a possibility of injury if a bag of waste charged from a upper floor strikes the door thus slamming it shut.

   2. Top hinged rubber baffles are available to close off the intake throat from the chute. Their main purpose is to help prevent backdrafts, however, they are not required if negative pressure is maintained in the chute.
   3. Sprinklers can be installed in the intake throats of the charging station if desired or required by local building codes.

II. Charging waste into the chute

A. Special waste restrictions

1. Infectious and pathological wastes, radiological wastes, toxic chemical waste and flammable solvents should not be put down the chute.
2. Separation of metals and glass might be considered to reduce noise in the chute, especially if there are offsets in the chute, and to reduce the possibility of injury to personnel in the discharge area from broken glass.

B. Waste should be placed in bags before being dropped down the chute to keep the chute as clean as possible, to prevent aerosolization in the chute or discharge area, and to prevent waste being scattered over the discharge area.

1. Requirements for bags

Most hospitals using gravity chutes place the small waste basket liners in a larger bag which when full is dropped down the chute.

  a. Bags should be strong enough to withstand impact at the bottom of the chute. It may be impractical (expensive) to find a paper or plastic bag that would never rupture, but if most wastes are contained in liners, the scattering of loose waste in the discharge area can be kept to a minimum.
  b. The size of the bag used is limited by the diameter of the chute and the size of the charging doors. These are not strict limits because the bags will elongate when dropped down the chute.

2. Type of bags
   a. Plastic or paper bags are used in most hospital chute systems. Their use permits automatic charging of waste to processing equipment such as a compactor, pulper or incinerator without further handling. Their limitations include the possibility that the bags could rupture from impact at the bottom of the chute or when a plug is being removed.
   b. Cloth bags will withstand the impact at the bottom of the chute and are easier to remove when plugged than the plastic or paper bags. However their use is not practical. The bags must be emptied at the bottom of the chute and cleaned frequently. Because they are porous, they do not effectively contain odors or bacterial aerosols.

III. Chute

A. Diameter

1. Diameters available from manufacturers vary from 12 to 36 inches. The National Fire Protection Association suggests that the chute should be at least 24 inches in diameter.[2]

B. Materials

1. A stainless steel chute is best because it is corrosion resistant, has no coating to wear off as do some other materials, and has high impact strength. Other materials used are galvanized or aluminum-coated steel. Chutes can also be constructed of masonary material but this material is harder to keep clean.[1]

2. NFPA standards require that there are no screws, rivets or projections in the interior of the chute to tear open bags or catch a bag and cause a plug.[2]

C. Maintaining negative pressure in the chute through the use of a small blower helps to prevent backdrafts of odors, dust or bacteria laden air. The location of the air exhaust should be away from patient areas and air intakes.

D. If possible, chutes should not have offsets because of the noise problem and the likelihood of plugging.

E. Sprinklers are usually required at the top of the chute and additional sprinklers at intermediate levels may be required in local building codes.[2]

F. Cleaning

1. If bags are used to contain the waste, the chute will stay fairly clean.

    2. Manufacturers offer a flushing unit for the top of the chute which can be used to rinse the chute, but it is not very effective. Manual washing or a mechanical washing device which moves down the chute is more effective.

IV. Chute discharge area

  A. NFPA standards state that the chute discharge should be located in a separate room.[2]

    1. Walls, floor and ceiling should have a fire resistant rating of not less than one hour, and the room should have an approved fire door.[2]

    2. Sprinklers, a hand hose and floor drains should be provided for fire protection and cleaning purposes.[2]

    3. The room should be at least large enough to contain a cart which can be placed under the chute discharge opening. However, it is recommended that the room be oversized to permit the possible addition of further processing equipment, such as a compactor or horizontal pneumatic tube.

  B. Discharge opening

    1. There should be a door at the bottom of the chute which is equipped with a mechanism which will automatically close the door in case of a fire in the chute or discharge area. A smoke detector mechanism is more sensitive than the fusable link mechanism which reacts to high temperatures.

    2. Type of opening

      a. The hopper type is used when the opening is built into a wall. If this type is used, the door should be left open so that the waste will fall into a cart or some other equipment. Bags can become plugged in the bottom of the chute if allowed to accumulate with the door closed. There is a definite danger of injury to personnel if the plug has to be pulled out by hand, and there is also the danger of fires in the chute.

b. The direct discharge type is used when the opening is in the ceiling. Waste drops through the opening into a container or processing euqipment. This could be very noisy and messy because of the force of impact shattering glass and bursting bags.

C. Connecting the chute to further processing equipment

1. In order to eliminate manual handling of waste at the bottom of the chute, many hospitals have the chute connected directly to other processing equipment such as compactors, pulpers or incinerators. Horizontal pneumatic tubes are being used to move waste from the bottom of the chute to further processing equipment some distance away.

V. Operation and maintenance

A. Control system

1. Charging doors should be electrically interlocked so that only one door can be opened at a time. An indicator light at each charging station would indicate to personnel that they should not try to open the door.

2. Manufacturers also offer a switch in the discharge area which will lock all charging doors so that no waste can be charged when containers are being changed or a plug is being removed.

3. Discharge openings should have doors that will automatically close when exposed to fire. Sprinklers should be provided at the top of the chute and at intermediate levels in the chute if required.

4. Slight negative pressure should be maintained in the chute and discharge area to prevent dust, odor and bacteria laden air from being diverted into the hospital.

B. Preventive Maintenance

1. Door gaskets and closing mechanisms should be checked periodically to insure that the doors are closing properly and tightly.

2. Electric interlock switches should be checked periodically to clean off any dust or dirt which might interfere with proper operation.

C. Cleaning

1. The charging room should be cleaned daily or whenever there is visible soil.

2. The discharge area should be cleaned daily to remove any waste that may have fallen on the floor. It is suggested that the room be hosed down periodically.

3. If bags are used, the chute should remain fairly clean. However, manual or mechanical methods can be used to clean the chute if desired.

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OPERATION GUIDELINES: PNEUMATIC CHUTE SYSTEM

There are three types of pneumatic systems: the total pneumatic system, the gravity-pneumatic system with valves, and the gravity-pneumatic system without valves.

In the total pneumatic system, the vertical risers and horizontal runs are under negative pressure. This type of system can handle both waste and soiled linen in either a single or double chute system. If a single chute system is used to transport both waste and soiled linen, a diverter valve is used to direct the waste or linen to the appropriate collection rooms.

The two gravity-pneumatic systems combine vertical gravity chutes with horizontal pneumatic chutes. These types of systems can be used if a sufficient air supply can be provided at the beginning of the pneumatic chutes.

In the gravity-pneumatic system without valves, the gravity chutes discharge directly into the pneumatic chutes. Double door charging stations and a diverter valve can be used with this system to allow the transport of both waste and soiled linen through the same chute. This system, as well as the total pneumatic system, can transport only one load of waste or linen at a time.

In the gravity-pneumatic system with valves, the gravity chute and pneumatic chute are separated by a valve. Waste accumulates at the bottom of the gravity chute, and periodically the valve opens depositing the waste into the pneumatic chute. Separate systems are required to transport waste and soiled linen through this type of gravity-pneumatic system.

I. Charging stations

  A. Location

    1. Pneumatic systems should be subject to the same requirements as gravity chute systems. Charging stations should be located in separate rooms and not in corridors for esthetic reasons and because of the possibility of smoke and bacterial aerosol backdrafts. National Fire Protection Association codes concerning the fire resistant construction of the charging rooms should also apply.[2]

    2. The charging room should be large enough to contain several waste receptacles. Some hospitals do not charge glass and metal into a pneumatic system because they produce noise in the chutes and because the glass could cause injury to personnel in the collection room.

  B. Type of charging station

    1. The size of charging doors should be limited in order to prevent the entry of items which might be too large to pass through the chute.

    2. Double door charging station

      a. A double door charging station is standard equipment in the total pneumatic system. The outer door opens to a receiving compartment which is separated from the negative pressure in the pneumatic chute by an inner door. When the outer door is closed and the charging mechanism is set, the inner door will open depositing the load into the chute. Only one load moves through the chute at a time.

b. A gravity-pneumatic system without a valve, used to transport both waste and linen in the same chute, must have double door charging stations to insure that the waste and soiled linen will be transported to the appropriate collection rooms. When waste or linen is placed in the receiving compartment and the charging mechanism is set, the diverter valve is adjusted and all stations which contain soiled linen will be emptied one at a time. The valve then readjusts and all stations with waste are emptied one at a time.

3. A single door charging station can be used with the two types of gravity-pneumatic system if the systems are to transport only waste or soiled linen. The charging doors must be electronically interlocked so that only one door can be opened at a time. This will prevent bags of waste being charged at one station from being struck by bags charged from an upper station. In the case of the gravity-pneumatic system without a valve, the interlocking mechanism is designed so that when a load is charged into the system, no other door will open until that load has traveled to the collection room.

4. Sprinkler heads should be provided in double door charging stations as protection against fires that could start while both doors are closed. Local building codes may require sprinkler heads for single door charging stations.

II. Charging waste into the pneumatic system

   A. Charging mechanism

      1. Double door charging stations are equipped with a push button or key mechanism to indicate to the control mechanism that a station is loaded and ready to be emptied. In the case of a system which handles waste and linen in a single chute, there is a separate button for waste and linen which indicates to the control mechanism how the diverter valve should be set.

      2. The control mechanism which empties the stations is set to check each station in sequence and empty those which have been loaded. In the case of the single chute for both trash and linen, the mechanism will empty all stations with soiled linen one at a time and then empty those stations with waste. A continuous loading option is available which will override the emptying sequence and allow collection personnel to charge several loads without waiting for the control mechanism to cycle back to their charging station. This option will also discourage personnel from overloading the charging station because they do not want to wait for the control mechanism to cycle back to their station.

   B. Special waste restrictions

      1. Infectious and pathological waste, radiological waste, toxic chemical and flammable solvents should not be put down the chute. Handling of these wastes is discussed in the guidelines for a manual collection system.

2. Some hospitals do not charge metals and glass into the pneumatic system because if they are not mixed with other wastes, they could produce a great deal of noise in the chutes. Glass broken during transport could cause injury if waste is handled manually in the collection room.

C. Waste should be placed in bags before being charged into the pneumatic system to help keep the chute clean, and to prevent aerosolization in the chute or collection room, and to prevent waste being strewn over the collection room. Loose waste could build up in the chute corners and on the deflector screen in the hopper in the collection room. The deflector screen deflects the waste out of the air stream into the hopper. It must be kept clean to maintain proper pressure in the system.

1. Requirements for bags

Small waste basket liners are usually placed in a larger bag which when full is charged into the pneumatic system.

a. Bags should be strong enough not to rupture because of impact from vertical drops and in corners. The negative pressure in the system can also rupture bags. Hospitals will have to experiment with different bags to find one that will suffice.

b. The size of the bag used is limited by the diameter of the chute and the size of the charging doors. These are not strict limits because the bags will elongate due to the pressure in the system.

2. Type of bags

   a. Plastic bags are usually used in pneumatic systems because they will conform to the shape of the chute which helps prevent plugs from forming in corners. It may be impractical (expensive) to find a bag which would never rupture in the system, but their use will help keep the chute and collection room clean. Paper bags can also be used but they are not as flexible as the plastic bags.

   b. Cloth bags will withstand the impacts and pressures in the system but their use is impractical. The bags must be emptied at the bottom of the chute and cleaned frequently. Because they are porous, they do not effectively contain odors and bacterial aerosols.

III. Chutes

A. Chute diameters available from manufacturers vary from 16 to 24 inches. Gravity chutes should be at least 24 inches in diameter and it is recommended that pneumatic chutes be 20 inches or more in diameter. There is a greater possibility of plugs forming in pneumatic chutes with diameters less than 20 inches.

1. If the chute is to be used to transport soiled linen, the chute should be 24 inches in diameter. The size and weight of the linen increases the possibility of plugs developing in chutes with smaller diameters.

B. A certain amount of noise is produced by the air stream in the chutes. This can be controlled by covering the chutes with insulation.

C. Although manufacturers claim that items traveling through the chutes do not touch the sides of the chute, the items do strike the chutes in corners. The chutes must be well supported at the corners or the force of the impact could loosen supports producing a great deal of vibration and noise. If left uncorrected, the supports could eventually work loose causing a collapse of the chute.

D. Plugs will occasionally develop in the chutes, usually in corners, offsets and inclines, because a load is either too large or too heavy to maneuver around these areas.

   1. Care must be taken in the layout of the pneumatic system to be sure that potential stoppage points are located away from such areas as central sterile supply, surgery or other areas where sanitation is critical.

   2. Access openings into the chute should be provided near potential stoppage points to permit removal of the plug. Many hospitals have been forced to cut openings into the chtues to remove plugs because manufacturers do not offer sections of chute with access openings. Unless these openings are well sealed, they will provide an air source which will diminish the negative pressure in the chute thus increasing the chances of a plug developing.

   3. Access openings to the chute should be provided at charging stations so that plugs which develop in the

vertical risers can be removed. The openings would make it easier to remove the plug than if personnel had to reach through the door of the charging station.

E. If wastes are bagged then the chutes should remain fairly clean. There is really no satisfactory method available to clean the chutes except for manually scrubbing them down which is difficult unless there are access openings into the chute.

IV. Collection room

A. Location

1. The linen collection hopper should be located in the laundry to cut down the amount of manual handling of soiled linen.

2. The waste collection hopper is often located in the room or building that houses the blower and other equipment.

a. National Fire Protection Association codes regarding the construction of the gravity chute discharge room should also apply to the pneumatic system collection room.[2]

b. The hopper can be connected directly to a loader for processing equipment such as an incinerator, compactor or pulper. It can also be located so that waste is deposited directly into hauling containers. This will eliminate the need for manual handling of the waste.

V. Operation and maintenance

A. The equipment used to run the pneumatic system is often located in a separate bulding because it takes up a great deal of space and because its operation can be quite noisy. The blower also produces a great deal of heat which must be controlled by proper ventilation. If the equipment room is located in the hospital, care should be taken to insure that it is sound-proof and properly ventilated. Sound attenuators will help control the noise produced by the blower and other equipment.

B. Exhaust air should be filtered to remove lint and dust before being released to the atmosphere. The exhaust duct should not be located near air intake vents or in the vicinity of patient areas.

C. Control system

1. If a plug goes unnoticed it could build up for quite a distance forcing the system to be shutdown for a long time in order to clear the plug. Electric eyes strategically placed throughout the system would help locate stoppages before they build up.
2. Electric eyes or other monitoring equipment should be used to locate malfunctioning equipment such as dampers or valves which have not opened or closed properly.
3. It is recommended that the control system include a graphic display of the pneumatic system. The display might show which station or riser was being emptied and might also have lights and alarms to indicate and pinpoint the location of a plug or any malfunctioning equipment.

D. Preventive maintenance

1. Charging stations

   a. Charging door gaskets should be checked periodically to insure that there is a proper seal to avoid air leakage and prevent noise caused by vibration.

   b. The mechanism for opening and closing the inner door of the double door charging stations should be checked periodically to insure that it is closing tightly and fast enough. If this mechanism is not working properly, there is the chance that a bag of waste from an upper floor could get caught on the door, thus producing a stoppage.

2. Chutes

   a. Chute supports must be checked frequently because vibration in the chute, especially in corners, can cause the bracing to become loose causing more vibration and eventual collapse of the chute.

   b. Gaskets which connect chute sections must be kept tight or the chutes will vibrate and eventually buckle from metal fatigue.

3. Other equipment which should be checked periodically includes air intake dampers which must work properly to provide a sufficient air supply to the system, the diverter valve if the system is a single chute linen and waste system, and the valve which separates the two chutes in the one type of gravity-pneumatic system.

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OPERATION GUIDELINES: INCINERATION SYSTEM

I. Incinerator

A. Location

1. The flow of waste to the incinerator should be considered when choosing a location to install the incinerator so that the majority of waste can be transported to the incinerator without having to pass near central sterile supply, the kitchen or other areas where sanitation is critical. The flow of gases out of the incinerator should also be considered to insure that the stack will be located away from patient areas, air intakes or obstructions.

2. If the incinerator is located within the hospital, National Fire Protection Association codes state that the incinerator should be enclosed in a room which is separated from the rest of the hospital by walls, ceiling and floor having a fire-resistance rating of not less than two hours. The room should only be used to store waste to be burned and possibly to house building heating equipment. The doors to the room should be approved, self-closing fire doors. NFPA codes require the installation of automatic sprinklers, and they also suggest having a hand hose connected to a suitable water supply which can be used in case of fires in the room and also to clean the room.[9]

3. If the incinerator is located outside the hospital it should be enclosed in a shelter. The shelter will protect the incinerator from the weather and help prevent paper and ashes

from being spread over the hospital grounds by the wind. It will restrict access to the incinerator to only authorized personnel, and with certain features such as sprinklers and fire resistant walls and ceiling, it should help contain any fires that might develop.

4. The room or shelter should be large enough so that there is ample room for temporary storage of waste, handling of ashes and nonburnables, and general maintenance on the incinerator. The room or shelter should also be large enough for the possible addition of pollution control equipment, incinerator loading devices, ash removal equipment or other auxiliary equipment.[6]
5. The room or shelter should be well ventilated to insure that there will be adequate air supply to the incinerator.
6. Floor drains and a hand hose should be provided for cleaning the room.

B. Type of incinerator

1. The Incinerator Institute of America has classified incinerators according to the type of waste they can burn, the pound per hour capacity of the unit and certain design characteristics (Tables H.1, and H.2).
2. Because of stricter air pollution codes and because the heating value of waste, measured in BTU/lb, is increasing due to the increased use of plastics, hospitals need a high temperature, multi-chamber incinerator.
   a. These incinerators are lined with several inches of refractory material which heats up as waste is burned

TABLE H.1

INCINERATOR INSTITUTE OF AMERICA CLASSIFICATION OF WASTES[7]

Type 0: Trash, a mixture of highly combustible waste such as paper, cardboard, cartons, wood boxes, and combustible floor sweepings, from commercial and industrial activities. The mixtures contain up to 10 percent by weight of plastic bags, coated paper, laminated paper, treated corrugated cardboard, oily rags and plastic and rubber scraps.

This type of waste contains 10 percent moisture, 5 percent incombustible solids and has a heating value of 8500 B.T.U. per lb as fired.

Type 1: Rubbish, a mixture of combustible waste such as paper, cardboard cartons, wood scrap, foliage and combustible floor sweepings, from domestic, commercial and industrial activities. The mixture contains up to 20 percent by weight of restaurant or cafeteria waste, but contains little or no treated papers, plastic or rubber wastes.

This type of waste contains 25 percent moisture, 10 percent incombustible solids and has a heating value of 6500 B.T.U. per lb as fired.

Type 2: Refuse, consisting of an approximately even mixture of rubbish and garbage by weight.

This type of waste is common to apartment and residential occupancy, consisting of up to 50 percent moisture, 7 percent incombustible solids, and has a heating value of 4300 B.T.U. per lb as fired.

Type 3: Garbage, consisting of animal and vegetable wastes from restaurants, cafeterias, hotels, hospitals, markets and the like.

This type of waste contains up to 70 percent moisture, up to 5 percent incombustible solids, and has a heating value of 2500 B.T.U. per lb as fired.

Type 4: Human and animal remains, consisting of carcasses, organs and solid organic wastes from hospitals, laboratories, abattoirs, animal pounds, and similar sources, consisting of up to 85 percent moisture, 5 percent incombustible solids, and having a heating value of 1000 B.T.U. per lb as fired.

Type 5: By-product waste, gaseous, liquid or semi-liquid, such as tar, paints, solvents, sludge, fumes, etc., from industrial operations. B.T.U. values must be determined by the individual materials to be destroyed.

Type 6: Solid by-product waste, such as rubber, plastics, wood waste, etc., from industrial operations. B.T.U. values must be determined by the individual materials to be destroyed.

TABLE H.2

INCINERATOR INSTITUTE OF AMERICA CLASSIFICATION OF INCINERATORS[7]

Class I:	Portable, packaged, completely assembled, direct fed incinerators, having not over 5 cu. ft. storage capacity, or 25 lbs per hour burning rate, suitable for Type 2 Waste.
Class IA:	Portable, packaged or job assembled, direct fed incinerators, 5 cu. ft. to 15 cu. ft. primary chamber volume, or a burning rate of 25 lbs per hour up to, but not including 100 lbs per hour of Type 0, Type 1, or Type 2 Waste; or a burning rate of 25 lbs per hour up to, but not including, 75 lbs per hour of Type 3 Waste.
Class II:	Flue-fed, single chamber incinerators with more than 2 sq. ft. burning area, suitable for Type 2 Waste. This type of incinerator is served by one vertical flue functioning both as a chute for charging waste and to carry the products of combustion to atmosphere. This type of incinerator installed in apartment houses or multiple dwellings not more than five stories high.
Class IIA:	Chute-fed multiple chamber incinerators, with more than 2 sq. ft. burning area, suitable for Type 1 or Type 2 Waste. (Not recommended for industrial wastes). This type of incinerator is served by a vertical chute for charging from two or more floors above the incinerator and a separate flue for carrying the products of combustion to atmosphere.
Class III:	Direct fed incinerators with a burning rate of 100 lbs per hour and over, suitable for Type 0, Type 1 or Type 2 Waste.
Class IV:	Direct fed incinerators with a burning rate of 75 lbs per hour or over, suitable for Type 3 Waste.
Class V:	Municipal incinerators suitable for Type 0, Type 1, Type 2, or Type 3 Wastes, or a combination of all four wastes, and are rated in tons per hour or tons per 24 hours.
Class VI:	Crematory and pathological incinerators, suitable for Type 4 Wastes.
Class VII:	Incinerators designed for specific by-product wastes, Type 5 or Type 6.

thus helping to maintain the high temperatures required in the incinerator to properly burn the waste. The refractory can heat up enough to ignite waste charged into the incinerator without the need of auxiliary burners.

b. The air needed to maintain combustion is provided by natural, induced or forced draft. Natural draft is produced by a pressure difference created by the stack due to its height and by a temperature difference between the stack gases and the atmosphere. Natural draft will usually require a stack 30 or more feet high. Induced draft is created by a fan in the stack which pulls air through the incinerator. Forced draft is produced by a blower in the incinerator which forces air through the incinerator and out the stack. With induced and forced draft, the stack need not be as high as that required with natural draft, although a high stack might be preferred to keep emission gases away from patient areas and air intakes.

c. The primary or burning chamber of the incinerator is of either grate or hearth design. Metal grates suspend the waste in the combustion chamber which permits an adequate air flow around the waste for complete combustion. With a hearth design, waste is deposited on the heated refractory where it is ignited and consumed. Hearths are often designed with air passages in the floor to provide additional oxygen for more complete combustion as well as eliminating the need for the potentially dangerous practice of stoking the fire.

d. A burner is usually provided in the primary chamber to help ignite the waste and raise the chamber temperature up to 1200° to 1800°F.[8] Once this is accomplished, the heat produced by the continuous burning waste should be sufficient to maintain proper temperature without the burner. Pyrometer heat sensors are used to monitor the temperature in the chamber and turn on the burner when required.

e. An auxiliary burner is sometimes needed in the primary chamber if waste with a high moisture content is to be burned. The burner helps dry out the moisture in the waste, keep the waste burning and maintain proper temperatures in the chamber. Auxiliary burners are required for the burning of pathological waste.

f. In the afterburner chamber, a burner is used to raise the chamber to temperatures around 1500° to 2200°F.[8] As the gases and unburned particulates pass through the chamber they are combined with air provided by a blower for complete combustion of the gases. A pyrometer heat sensor can be used to shut off the afterburner if the heat produced by the combustion of the gases is sufficient to maintain proper temperature in the chamber.

g. Many manufacturers claim that after passing through the afterburner chamber, the gases should be able to pass out of the stack without further treatment and still remain within federal particulate and visible emission standards.

> Incinerators with capacities less than 200 lb/hr should not emit more than 0.3 grain

> of particulate matter per standard cubic foot of dry flue gas corrected to 12 percent carbon dioxide. Incinerators with capacities greater than or equal to 200 lb/hr should not emit more than 0.2 grain of particulate matter per standard cubic foot of dry flue gas corrected to 12 percent carbon dioxide.
>
> For existing units, except during startup, the density of any emission to the atmosphere should not exceed Number 2 on the Ringelman Scale or Public Health Service Smoke Inspection Guide. For new units, except during startup and stoking, the density of any emission should not exceed Number 1 on the Ringelmann Scale or Public Health Service Smoke Inspection Guide.10

However, further emission control equipment may be needed. Types of particulate and gaseous emission control equipment include wetted baffle spray systems, cyclone filters, wet scrubbers, electrostatic precipitators and fabric filters.

3. In sizing an incinerator, the type and amount of waste generated in the hospital, the method of collection, and the hours of incinerator operation per day should be considered.

   a. Most manufacturers list the pound per hour capacities of their incinerators for the various types of waste as classified by the Incinerator Institute of America, but these types may no longer apply to hospital waste. The heat value of hospital waste, measured in BTU/lb, is increasing due to the increased use of plastics. From 1955 to 1965 the heat value of hospital waste rose from 2500 BTU/lb, which is the heat value of Type 3 waste as defined by the I.I.A., to 6500 BTU/lb, which is the heat value of Type I waste. It is predicted that by 1975 the heat value will rise to 14,000 BTU/lb.[4]

b. As the heat value of the waste increases,the quantity of waste charged into the incinerator per hour must be decreased to keep the incinerator from overheating and damaging the refractory material. There is a need for manufacturers and government testing groups to rerate the lb/hr capacities of incinerators when incinerating wastes with higher heat values.

c. Some manufacturers suggest that their units be operated no more than 6 hours per day and others feel their units can be operated 16 or more hours per day. However, when deciding on hours of operation, hospital management should consider the time required to warm up the incinerator which is about one hour and the time required to cool down the incinerator which could take eight hours. Time must also be set aside for ash removal unless the incinerator is equipped with a device to remove the ashes automatically. Ashes should not be removed or maintenance should not be performed inside the incinerator until the unit has cooled down completely.

d. The general procedure used to determine the incinerator capacity required for a hospital is to take an estimate of the amount of waste to be burned per day divided by the number of hours of planned incinerator operation per day. This figure may not present a true picture. The method of waste collection and transport to the incinerator should also be considered. Depending on the method used, waste could be collected and brought to the incinerator continuously during the day or only twice a day. If the incinerator is sized using the method described above, but the waste is collected and brought to the incinerator only twice a day, a great deal of storage space will be needed to hold the waste until it can be charged into the incinerator.

   e. Because the total weight, as well as the heat value, of solid waste generated in a hospital is increasing due to the trend toward single-use items, the incinerator should be oversized to handle future increases.

4. A control system which will automatically take the incinerator through the burning cycle is preferable to manual operation. Listed below are features which might be included in the control system.

   a. The incinerator should be automatically purged of any residual gases prior to start up to prevent explosions.

   b. Dampers and blowers should be automatically controlled to provide appropriate draft to the primary and afterburner chambers. Draft indicator gauges will help the operator monitor the air flow to insure that it is sufficient for proper combustion.

c. The use of pyrometer heat sensors with the burners in the primary and afterburner chambers provides automatic control of the temperatures in the two burning chambers. Their use will limit fuel usage because the burners will ignite only when the heat produced by the burning waste and gases is insufficient to maintain proper temperatures in the burning chambers. A means for operator monitoring of the temperatures in the burning chambers should be provided to insure that the temperatures are high enough to properly burn the waste but not too high to damage the refractory. A water fog spray, also controlled by a heat sensor, can be used to cool the chamber if it overheats.

d. Low voltage protection should be provided for the blower and other motors, otherwise the motors could overheat and burn out if the voltage drops below a certain level.

e. To insure proper and safe operation of the incinerator the above mentioned factors should be connected with a gas solenoid shut-off valve to provide immediate system shut down in case any of the above mentioned functions should fail.[8] A smoke sensor in the stack connected with an alarm could be used to monitor stack emissions.

f. If the charging door is to be opened during the burning cycle, certain precautions should be taken to diminish the chances of blowback of gases. Maintaining positive pressure in the incinerator room in relation to the pressure within the incinerator is one method. Some manufacturers provide an air curtain around the charging door to prevent blowback of gases.

II. Charging waste into the incinerator

A. Method of charging

1. Manual charging is commonly used with smaller incinerators, but in order to realize the rated capacity of incinerators having capacities greater than 500 lb/hr, automatic charging devices should be provided. Manual charging is time consuming because the operator can only lift so much waste into the incinerator at a time. The operator also faces possible injury from handling the waste as it is charged from the blowback of flames and from exploding aerosol cans. If manual charging is to be performed, the operator should wear gloves and goggles to provide him with some protection.

2. Some incinerators can be provided with a charging chute which is a tube through the incinerator wall but separated from the burning chamber by a guillotine type door. Waste is deposited in the chute and pushed into the incinerator with a plunger when the door is opened. This arrangement allows a larger volume of waste to be charged at a time and provides greater protection for the operator because he does not have to approach as close to the opened charging door as with manual charging.

3. Flue-fed incinerators, where the stack is also used as a gravity chute for charging waste into the incinerator, are not appropriate for hospital installations. Gravity

chute feeding directly to the incinerator is also inappropriate because the combustion gases may be diverted up the chute rather than to the stack and might even get into the hospital. There is also a definite danger of fires in the chute.

4. Another method of charging is a mechanical device which lifts and dumps a container of waste into the incinerator. This arrangement allows for the charging of a large volume of waste but increases the chances of the blowback of gases and burning materials. There is also the possibility of spillage of waste onto the incinerator room floor as the container is dumped into the incinerator.

5. A ram or compactor feeder consists of a hopper where waste is deposited and possibly compacted and a hydraulic ram to push the waste into the incinerator. The hopper should have a cover which is interlocked with the guillotine incinerator charging door so that the incinerator door will not open unless the hopper door is closed. This will prevent the blowback of gases and flames out of the hopper. After the ram has pushed the waste into the incinerator, it should retract to a position just in front of the incinerator door which closes before the ram fully retracts. This should prevent the blowback of any flaming materials which could start a fire in the hopper when waste is placed in it. Because of the danger of fires, waste should not be stored in the hopper for long periods of time.

B. Special waste restrictions

1. Flammable solvents or toxic chemicals should not be charged into the incinerator because of the danger of explosions. A private contractor who has the equipment to dispose of these wastes could be hired to haul them away.
2. The costs of the equipment needed to safely incinerate radiological waste are prohibitive for the individual hospital. The flue gas and ashes must be given special handling to prevent release of radioactivity to the atmosphere and to protect personnel.
3. The incineration of noncombustibles as well as combustibles is desirable from the standpoint of treatment of the waste. However, the charging of large amounts of noncombustibles decreases the weight of combustibles that can be charged per hour and increases the amount of residue that must be removed from the incinerator. Certain noncombustibles such as aerosol cans should not be charged into the incinerator because of the possibility of explosions which could injure the operator or damage the refractory.
4. Certain state codes require that pathological and animal waste be incinerated. Because of the high moisture content of these wastes, auxiliary burners are required in the primary chamber for drying and burning the waste. Instead of providing auxiliary burners in the large general waste incinerator, the hospital might consider having a separate pathological incinerator.

a. When burning pathological waste that has been preserved in alcohol, there is a problem of providing enough air to keep down the heat and smoke. Using the auxiliary burner to heat the primary chamber to approximately 1700° and then burning the waste with the burner shut off and the blower running is one method that has been suggested.[8]

b. Phosphorus deposits from bones can build up on the grate or hearth, and because they are hard, the deposits are difficult to remove. The deposits can also shut off air passages through the grates and hearth.[8]

5. The type of plastics used in hospitals are principally thermosetting and thermoplastic. Thermosetting plastics which are hard plastics such as bakelite and melamine, are easily burned if subjected to sufficiently high temperatures. Thermoplastics which are softer plastics can cause some problems in incinerators. If charged in large quantities they will melt and could extinguish the fire by covering gas jets and blocking air passages. Polyvinyl chloride produces hydrochloric acid gas when burned which can corrode metal work in the incinerator. The high heat value of plastics can cause overheating problems in the incinerator if large quantities are charged at one time.[5]

III. Ashes should not be allowed to accumulate in the incinerator because they could plug air passages in grates and hearth. The incinerator and ashes should be cooled overnight before attempting to remove the ashes to prevent possible injury to personnel and damage to refractory. Dampening the ashes slightly before they are removed from the incinerator will help settle dust. However the operator should still wear a dust respirator. If rakes or shovels are used to remove ashes from the incinerator, care should be taken not to strike the refractory because it could crack. The ashes should be placed in a fireproof container which has a cover.

IV. Operation and maintenance

- A. An operator should be provided to charge waste into the incinerator or loading device, to monitor the operation of the incinerator, to remove ashes, to keep the incinerator area clean and to perform some of the preventive maintenance work. The operator should be required to wear gloves and goggles which provide some protection when charging waste into the incinerator.
- B. Preventive maintenance
  - 1. Incinerator
    - a. Gasketing around doors should be checked periodically and screw down handles and hinges should be lubricated periodically to insure that the doors open, close and seal properly.
    - b. Burners should be checked daily to keep the spark electrode and gas jet clean.
    - c. Lint and dust can hamper the operation of blowers and dampers. They should be cleaned and lubricated periodically.
    - d. Air tubes from the blowers should be inspected periodically

for holes and cracks which should be patched immediately. Air passages in the refractory should be cleaned daily or whenever ashes are removed.

e. Refractory should be checked periodically, and any cracks or dislodged material should be repaired before metal structural parts are exposed to the heat of combustion. Refractory is designed to crack somewhat to allow for expansion when heated, and if refractory is over patched, additional cracking might occur. If a hot spot, a difference in color of paint caused by heat, is noticed on the metal shell of the incinerator, refractory patching should be done as soon as possible. If not, metal could warp dislodging more refractory and making it difficult to patch.[8]

f. Daily removal of ashes and cleaning of the incinerator area is recommended.

2. Automatic feeders

   a. The feeder hopper and surrounding area should be cleaned daily to prevent odors and to remove any debris which might accumulate around the motors and hydraulic pumps.

   b. If the feeder is hydraulic, fluid level and fittings should be checked and moving parts should be lubricated periodically.

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OPERATION GUIDELINES: COMPACTION SYSTEM

Hospital compaction systems are usually of three types, and a single hospital might utilize one or more of the types. One system makes use of small vertical compactors which have motors with less than two horsepower and which compact waste into plastic bags or boxes. These units could be located at various points throughout the hospital to compact waste at the points of generation. Another system utilizes one or more stationary compactors which have motors with less than 10 horsepower. These compactors are often located within the hospital usually at the bottom of a gravity chute. Waste is compacted in metal containers having capacities of less than 5 cubic yards. When the container is filled, it is rolled to a point where it can be emptied into a hauling vehicle for transport to the landfill. Several manufacturers offer a medium size compactor such as this which compacts waste into plastic bags. The third system makes use of one or more stationary compactors which have motors with 10 or more horsepower, and which compact waste into large metal containers with capacities up to 45 cubic yards. The compactor and container are usually located near the loading dock where waste is brought for compacting. When the container is full, it is loaded onto a special vehicle and hauled to the landfill for dumping.

I. Compactor

  A. Location

    1. Small vertical compactors can be used in various areas of the hospital to compact waste at or near the points of waste generation. At the nursing stations the small

compactors could be used to compact the waste collected from patient rooms to reduce the volume of waste that must be transported through the hospital and to reduce the number of trips required to move it. In the kitchen or cafeteria the small compactor could be used to compact the garbage which is not sent to the garbage disposals; the cans, bottles, and other packaging wastes which are generated when preparing meals, and the milk cartons, napkins, and other waste which are returned to the kitchen on patient trays after a meal. If the kitchen makes use of single-use items such as cutlery, dishes and possibly trays, the small compactors will help reduce the volume of waste generated by the use of these single-use items.

a. The plastic bags or boxes into which the waste is compacted are heavy when full, weighing 50 to 100 pounds, and may require two men to remove them from the compactor and place them in a cart for transport.

b. The small compactors can be placed out in the open at the nursing station, hospital cafeteria or other points of waste generation only if there is a key-lock mechanism to limit operation of the compactor to authorized personnel.

2. If the stationary compactors are to be located within the hospital, they should be installed in a separate room with a door. The room should be constructed of fire resistant materials having a fire resistant rating of at least one hour. The room should be well ventilated,

and floor drains should be provided so that the compactor and room can be cleaned.

a. If the compactor is located within the hospital below a gravity or pneumatic chute, the containers of compacted waste will have to be moved out of the hospital to a point where they can be emptied into a hauling vehicle. The containers should be leakproof and totally enclosed to prevent odor, spillage or liquid seepage problems as the containers are moved out of the hospital.

b. A large stationary compactor is often located in a room in the hospital and connected through the wall to the container which is situated outside. This protects the compactor and personnel who charge it from the weather. The compactor is usually located in the loading dock area because of the noise associated with loading and unloading the container of compacted waste on a truck for hauling to the landfill.

3. If the compactor and container are to be located outside the hospital, the compactor should at least be covered by a roof to offer some protection from the weather for the compactor and for those charging it.

B. Type of compactor

1. Because of the nature of hospital solid waste, balers are not appropriate to handle general hospital waste, but could be used to bale paper and boxes or metal cans for sale to recycling plants.

2. Certain characteristics of the compaction equipment should be considered when sizing and selecting a unit. The National Solid Wastes Management Association has developed rating criteria to aid in comparing the various technical and performance characteristics claimed by manufacturers.[1]

   a. There are three methods of compaction: compaction in the container, compaction in the hopper, and compaction in both the hopper and container. Compaction in the container is a method where the ram pushes the waste deposited in the hopper into the container. As the container begins to fill, the waste being pushed in is compacted against the waste already in the container. Compaction in the hopper is a method where the ram compacts waste against a door which separates the hopper and container. The door is then opened and the compacted waste drops or is pushed into the container. This method offers a higher degree of compaction than compaction directly in the container. Compaction in both the hopper and the container is a method where, after the waste is compacted in the hopper, the door opens and the waste is compacted into the container. This method offers the highest degree of compaction of the three methods.

   b. In sizing a compactor, the hopper opening should be at least as big as the largest piece of material that will be thrown into it. If the waste is brought to the compactor in carts, the hopper capacity should be as large as the capacity of the cart. This is necessary to prevent spillage if a mechanical loader is used to lift and dump the contents of the cart into the hopper. If waste is charged manually and the hopper is large enough, the janitor need not wait for more than one compaction cycle to charge his entire load.

c. The cycle time or the time it takes the compactor to compact one load should not be too long so that it forces personnel to wait long periods of time between loadings of the hopper.

d. A useful characteristic in sizing compaction equipment which combines the hopper capacity and cycle time is the machine volume displacement per hour. It is defined as "the number of cubic yards per hour of material that can be processed by the machine at 100% utilization, continuous cycling of the machine."[1] It is the product of the hopper capacity and the number of cycles per hour. However, it is not a realistic measurement of the compactor capacity per hour because it does not take into account the amount of time required to load the hopper between cycles.

e. As a measure of the compaction force, manufacturers often state the total pounds of force exerted by ram. This figure is not very useful because ram face area can vary significantly for various units. A more realistic measurement of the compaction force is the pounds per square inch exerted by the ram. It is calculated by dividing the total ram force in pounds by the ram face area in square inches. Another measure of the compaction force which has been suggested is the "Force Factor" which equals the ram force in pounds divided by the cubic foot volume of the hopper.[3]

f. For a particular manufacturer's line of compactors, increasing the horsepower of the motor usually increases the volume displacement per hour because the hopper capacity and/or ram size are also increased. If the hopper capacity and ram size remain constant, increasing the horsepower of the motor will increase the pound per square inch compaction force.

g. Another characteristic which is particularly important when waste is compacted in the container is the ram penetration into the container. It represents the "portion of the forward ram stroke available for final compaction of the waste load in the container."[1] The ram should penetrate at least several inches into the container so that waste does not build up at the mouth of the container where it could fall out when the container is disconnected from the compactor.

3. It is recommended that certain features be included as part of the compaction equipment.

   a. As a safety precaution many manufacturers include an emergency stop button so that the operator can stop the compaction cycle. A more effective means of controlling the compaction cycle is a "dead man switch" which forces the operator to push a buttom during the entire compaction cycle. If he removes his hand the compactor will stop. Without this feature, the operator could be seriously injured if he became entangled in the compaction mechanism and was unable to reach the emergency stop button.

b. The hydraulic cylinder should be covered to protect the mechanism from dirt and grit.

c. The unit should include controls that will shut off the compactor if something jams the mechanism, to prevent damage to the hydraulic system.

d. The hopper should have a drain which should be located over a floor drain so that liquids can flow out.

e. Many compactors include a system which introduces a deodorizer into the hopper during the compaction cycle. This should definitely be included as part of the small vertical compactors which are usually located out in the open in hospitals. The system is also useful in controlling odors around the containers connected to the stationary compactors which hold compacted waste for several days before they are emptied.

4. Another feature which is available from several manufacturers is an automatic signal, a buzzer or light, which indicates when the container is full.

5. Some manufacturers offer a system which combines a shredder and a compactor. This system produces a higher degree

of compaction for a given pressure than the other methods of compaction. However the operation of a shredder is noisy, and there are more restrictions on the types of waste that can be charged to a shredder than to a compactor.

II. Charging of waste into the compactor

  A. Method of charging

    1. Manual charging is time consuming because the operator can only lift so much waste into the compactor hopper at a time. He also faces possible injury from handling the bags of waste. Large stationary compactors are often installed at loading docks so that the hopper opening is at floor level which helps eliminate the strain of lifting bags of waste into the hopper. In this situation carts which can be manually dumped into the hopper could be used.

    2. There are systems available which will lift and dump the contents of specially designed carts into the hopper. This eliminates the possibility of injury to the operator from handling the waste or the possibility of the operator falling into the hopper if the hopper is at floor level. The hopper must be large enough to accept the contents of the cart so that it does not overflow onto the floor.

  B. Special waste restrictions

    1. Infectious and pathological waste, radiological waste, toxic chemical waste and flammable solvents should not

be charged into the compactor but they should be disposed of by other means.

2. Large quantities of leachate from waste with a high moisture content could drain out of the hopper and container and cause a nuisance in the compactor area. Liquids could also drain out as the container is hauled. Drains in the hopper, floor drains and water tight containers will help control the problem.

3. If garbage is placed in the compactor, the container of compacted waste should be emptied daily to prevent odors.

III. Containers

A. Type of container

1. Whether the container is a plastic bag or box or a metal container it should be leakproof.

2. Metal containers should have a leakproof and air tight door which fits over the opening when the container is disconnected from the compactor. The container should be designed so that the opening is not at the bottom of the container where liquids could leak out. A capped drain on the container would be useful for draining out liquids before hauling and for cleaning the container.

B. Size of the container

1. The size of the container to be used depends on the type and size of the compactor, its location and the equipment available to the hauler. Manufacturers will usually indicate a range of sizes of containers that can be used with their various units.

2. Metal containers should be sized to hold waste for no more than one week, and if garbage is compacted, the container should be emptied daily to prevent odors.

IV. Operation and maintenance

A. Operator

1. It is not necessary to have an operator on duty at all times if access to the compactor is limited to authorized personnel and if there are safety controls to shut down the compactor in case of a malfunction.

2. One person should have responsibility for cleaning the compactor and surrounding area and perform some of the preventive maintenance. If several containers are filled during the period between haulings, this person should be in charge of removing the filled containers and setting an empty container in place.

B. Preventive maintenance

1. Cleanliness of the area around the compactor

a. The use of a deodorizer during the compaction cycle will help control odors.

b. The area around the compactor should be swept and washed daily to remove any waste or liquids which have fallen on the floor.

c. The compactor hopper should be scrubbed at least daily. Other parts of the compactor may need cleaning to remove any waste which might have fallen on the unit.

d. Containers should be cleaned whenever they are emptied.

2. The National Solid Wastes Management Association has developed a bulletin describing the operation and some of the maintenance problems associated with hydraulic compactors.[2]

   a. The hydraulic pump creates the pressure which moves the hydraulic cylinder and compaction ram. The pressure developed depends on the pump output which is measured in gallons per minute. Proper operation of the pump is important to achieve the desired compaction force. Some conditions which could indicate a malfunction in the pump are noise which could be caused by wear or damage from impurities in the hydraulic fluid, and reduction in operating pressures.[2]

   b. The reservoir is used to store the hydraulic fluid and remove impurities which could cause damage to components of the hydraulic mechanism. The reservoir should also dissipate heat from the fluid and remove air bubbles which can decrease compaction power because they are compressible in the hydraulic system.[2]

   c. The hydraulic fluid which is oil acts as a lubricant as well as the medium for the creating of the compaction force. The oil should have high antiwear characteristics and should contain antirust and antioxidation agents. The viscosity of the oil is important for adequate sealing and lubricating at the operating temperature of the unit. The oil should be changed regularly according to manufacturer's specifications.[2]

d. The movement of the hydraulic cylinder is controlled by valves. A relief valve protects the mechanism from excessive pressure if the ram jams or maximum compaction forces are achieved. A check valve controls the displacement of the ram. Control valves regulate the flow of hydraulic fluid to and from the hydraulic cylinder. The seal in the cylinder should be checked periodically to protect against oil leakage. Valves should also be checked periodically to insure proper operation of the hydraulic system and to prevent damage to any of its components.[2]

3. Container

a. The shackles which secure the metal containers to the compactor may need replacement periodically.

b. Metal containers, especially those which are emptied into trucks, receive a good deal of abuse during loading and unloading. They should be checked periodically for bulging sides and cracked welds which destroy the ability of the compactor to compact refuse up to specifications.[3]

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OPERATION GUIDELINES: WET PULPING SYSTEM

Wet pulping is the grinding of material in a water bath to produce a slurry which is pumped through pipe to a unit which squeezes out some of the water and recycles the water to the grinding unit. The resulting pulp is semi-dry and reduced in volume by 50 to 60 percent.[1] However its weight is much greater than the original material due to the residual water content. The pulp is usually hauled away, although some communities might be hesitant to accept pulp at the landfill because of the possibility of leaching of contaminants into the surrounding soil and subsurface water supply.[2] Incineration of pulp is a possibility although difficult because of the moisture content of the pulp. Discharge of the slurry to the sewer is usually not permitted because of the added load it puts on sewage treatment facilities.

I. Pulper

  A. Location

    1. The pulper should be located in a separate room or isolated area which is constructed with some degree of sound proofing and is well ventilated. A water supply and floor drains should be provided to facilitate the cleaning of the room.
    2. Pulpers used in the kitchen should be located away from food preparation areas because of the possibility of aerosols. A pulper is capable of handling a wider variety of kitchen wastes than small garbage grinders and can be used in place of grinders if the local community does not permit ground waste in the sewer system.

3. In order to take advantage of the transport capabilities of a pulping system, pulpers for general waste are usually installed at a central location in the hospital to minimize the horizontal distance that waste must be transported to the pulper. The slurry is then pumped to the water extractor which deposits the pulp in a hauling container or a loader to an incinerator.

B. Type of pulper

1. The pulper is made up of an enclosed pulping tank, the shearing mechanism and main motor, slurry pump and necessary piping. All wettable parts should be stainless steel.

2. Nonpulpable materials such as hard metal and glass which produce severe equipment wear are removed from the pulper by a junk extractor. Heavy materials such as glass and metal settle to the bottom of the pulper from where they are gathered in small buckets attached to a conveyor chain which moves the buckets to a position where they can empty into a container.

3. A water level control mechanism insures that there is sufficient water in the pulper and resulting slurry to prevent stoppages in the piping. Although water is recycled to the pulper from the water extractor, a certain amount of water remains in the pulp and is replaced in the pulper by fresh water. In this way the water does not become so saturated with suspended solids that it foams and heats up..

4. It is recommended that certain other equipment also be included as part of the pulper.
    a. Manufacturers offer an injector to add a deodorizing solution to help control odors in the pulp. This will permit the storage of pulp for several days without odor problems. The deodorizing solution is not very effective when added to pulped garbage which decomposes rapidly.
    b. A sensor timer device is available which will automatically start the unit when waste is charged into the pulper. The device will also shut down the unit if no waste is deposited into the pulper over a certain period of time. In this way the unit does not run continuously if there is no waste to pulp.

II. Charging waste into the pulper

A. Method of charging

1. Pulpers can be connected directly to gravity chutes but this is not recommended because it does not permit regulation of the amount of waste fed at one time which makes overloading possible. A better system would include a motorized conveyor from the chute to the pulper which should include a load control mechanism to regulate feeding. This type of system increases the possibility that nonpulpable materials might be charged into the pulper. With manual charging there can be better control over the types of waste charged, but the personnel are subject to possible injury or infection.

B. Special waste restrictions

1. Infections and pathological waste, radiological waste, toxic chemical and flammable solvents should not be charged to the pulper. Handling of these wastes is discussed in the guidelines for a manual collection system.

2. Large quantities of metal and glass, usually in the form of cans and bottles, should not be charged into the system. These materials produce severe wear and tear on the shearing mechanism, piping and water extractor. One reference indicates that new material and heavier designs have improved the reliability of the equipment.[3]

3. Previously cloth and filmy plastic were difficult to pulp and would ball up in the shearing mechanism forcing frequent cleaning and possibly jamming the mechanism. Improved shearing mechanism design has overcome this problem if these wastes are not charged in large quantities.[3]

III. Piping

A. Piping carrying the slurry from the pulper to the water extractor is usually three to four inches in diameter. The piping which returns the extracted water to the pulper need not be as large.

B. Piping should be equipped with cleanout fittings so that the pipes can be cleaned occasionally to diminish the possibility of plugs developing in the pipe. One manufacturer suggests fittings every 60 feet. Fittings should also be located near corners where plugs could occur.

IV. Water extractor area

A. The water extractor should be located in an area where the pulp can be deposited directly into the hauling container or into a loader to an incinerator. The area should be provided with a water supply and floor drains to facilitate frequent cleaning of the area.

B. Hauling of pulped waste to a landfill is the usual method of disposal, although some communities might hesitate to accept pulped waste at the landfill because of the possibility of leaching.

1. The pulp should be hauled daily if dietary waste is deposited in the container because pulping of dietary waste does not slow down the decomposition of the waste and resulting odor and insect problems.

2. If dietary waste is not pulped and stored in the container and if a deodorizer solution is used in the pulping process, the pulp can be allowed to accumulate three to four days without an odor or insect problem developing.

3. Although pulping reduces the volume of the waste, it significantly increases its weight. This fact may limit the size of the container which can be used for hauling because of load limits on roads.

4. Freezing can be a problem in some areas because it is difficult to remove frozen pulp from storage containers. A temperature controlled shelter would overcome this problem.

C. Pulp can be incinerated, but because of the moisture content of the pulp it is necessary to have auxiliary burners in the incinerator to dry out the pulp before it can be burned. These burners increase fuel costs. For a uniform charging rate, the pulp should be deposited in an automatic, regulated loader to the incinerator.

V. Operation and maintenance

A. Control System

1. Operation of a pulping system can be nearly automatic.

a. Gravity chute can be connected to a mechanical conveyor with controls to avoid overloading. A sensor, timer device will only operate the pulper when there is waste to pulp. Having the water extractor deposit the pulp directly to the hauling container or incinerator loader will eliminate manual handling of most waste once it has left the patient floors.

2. An operator is required to start up the pulper in the morning and shut down the unit at night. Someone must be responsible for transporting material ejected by the junk extractor to the hauling container. If the pulper is charged manually, a specific operator should be designated who is aware of the types of waste which should not be charged into the pulper.

B. Preventive maintenance

1. A stock of spare parts should be maintained to cut down the time the system is inoperable due to breakdowns. Manufacturers can assist hospital personnel in developing a list of spare parts which should be stockpiled. Because

of the number of moving parts in the system, a specific schedule for lubrication should be set up in conjunction with manufacturer's suggestions.

2. Pulper
   a. The shearing mechanism should be checked periodically to remove any fibrous or plastic materials which could impede the cutting teeth of the shearing mechanism and to see if any cutting teeth need replacing. Frequency of replacement of cutting teeth will vary depending on the amount of abrasive materials which are charged into the pulper.
   b. Other components of the pulper such as the impeller, security ring and bearing should be checked periodically for wear and tear caused by abrasives.
3. Junk extractor
   a. The conveyor chain should be checked periodically. The small buckets attached to the chain can work loose or may need replacement due to wear and tear.
4. Water extractor
   a. The water extracting screw and screen should be checked periodically for wear and tear caused by abrasives. The frequency of replacement of these parts will depend on the amount of abrasives that are charged into the system.
   b. The impeller in the water return pump will need maintenance occasionally due to the abrasives that are charged into the pulper.

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OPERATION GUIDELINES: WET GRINDING SYSTEMS

Most hospitals use wet grinding units in the kitchen to dispose of garbage and certain other waste such as milk cartons, paper cups, napkins and plastic jelly containers. Some hospitals also make use of wet grinding units to dispose of certain pathological waste such as placental waste. Heavy duty wet grinders with a hammermill grinding mechanism have been designed for use in research laboratories to dispose of small animal carcasses, soiled bedding, etc.

The use of heavy duty wet grinders of the fixed impeller design to dispose of biological waste and the increasing volume of single-use items now used in hospitals was studied by Weintraub and Kern in 1969.[3] Their results and recommendations form the basis for this set of operation guidelines for a hospital wet grinding system. Wet grinding should not be confused with pulping which is considered in another set of operation guidelines.

Before any grinding system is installed, the hospital should consult with local authorities to see if ground waste is permitted in the sewerage system.

I. Wet grinder

  A. Location

    1. Whether grinder is for kitchen waste or for other hospital waste, it should be located near the points of waste generation.

    2. There should be ready connections for water, sewer and power, and the water and sewer lines should be large enough to provide sufficient water and rate of

flow in sewer lines to diminish settling of ground waste.

3. The grinder should be located so that it is easily accessible for maintenance.
4. Grinders used in the kitchen are most commonly found in the food preparation, dishwashing, and potwashing areas. Care should be taken to locate the kitchen grinders, which handle waste from returned food trays, away from clean areas because of the possibility of aerosol generation.
5. Grinders used for other than kitchen waste should be located in a separate room or in an isolated area of the hospital.
    a. The room should be constructed with some degree of sound proofing, or the isolated area should be chosen so that the noise will not disturb personnel and patients in other areas of the hospital.
    b. Floor drains should be provided for cleaning and in case the grinder becomes clogged and overflows.
6. Grinders are frequently installed in sinks. However, in large volume operations, installing a grinder in a sink removes the sink from use for other purposes during much of the day. A better placement is in a stainless steel table or drainboard.[2]
    a. The table should not be free standing but be fastened securely to the wall to diminish vibration and noise.
    b. The use of rubber or plastic in joints, legs, table

screws and in parts of the grinder itself to eliminate metal to metal contact will help to diminish vibration and noise.

B. Type of wet grinder

1. There are basically two types of grinding mechanisms.[3]

   a. The fixed impeller type has a flywheel, with stationary cutter blocks, which revolves at high speed impelling the waste by centrifugal force into a shearing ring. When the waste is ground sufficiently, it passes through gaps in the shear ring into the sewer line.

   b. The hammer mill type has rotating hammers which shatter waste at high speed until the particles are small enough to pass through holes into the sewer line.

   > "Hammer mills simply cannot successfully grind solid materials, particularly plastics, metal and other inorganics and synthetics. One major manufacturer describes this problem as the 'ping-pong effect', where solid materials bounce endlessly within the hammer mill with no significant change."[3]

2. Local communities, which allow the disposition of ground waste into the sewer system, will usually require that the grinder pass certain minimum requirements for fineness of grinding. For example, the city of Los Angeles requires that 100% of the ground material pass through a 1/2" screen, that 65% pass through a No. 3 sieve and that 40% pass through a No. 8 sieve.[3] Local authorities may also require minimum sized water and sewer lines.

3. It is recommended that the grinder include the following

features:

  a. Impeller and flywheel constructed of corrosion resistant materials.
  b. A shaft that can withstand the stresses produced when grinding materials such as hard plastic or rubber.
  c. A dual direction switch for running the motor in either direction to unjam the machine.
  d. Motor should have overload protection.
  e. Water flow into the grinder should be monitored, and the grinder should automatically shut off if the rate of water flow is not sufficient, in order to diminish the chances of a clog developing in the discharge line to the sewer. This can be accomplished by a solenoid shut off valve in the water line.
  f. A time delay relay switch which will let water run for a period after the grinder has been shut off will insure clearing of the discharge lines.
  g. For grinders used for disposal of waste other than kitchen waste, a water spray directed into the grinder would help prevent the backflow of materials and aerosols which could be harmful to the operator.

4. Grinders are often equipped with a rubber gasket over the grinder opening to help cut down noise and aerosol ejection. Light materials can settle on the gasket and have to be pushed into the grinder, usually by hand. This could be very dangerous if the grinder is used to dispose of needles and syringes or disposable razor blades.

a. If the grinder is used to dispose of waste other than kitchen waste, the grinder should have a covered feeding throat which has a hole through which to charge the waste.

- The feeding throat can be cone shaped or an offset chute so that the hole in the cover does not have to be directly over the grinder opening. This helps cut down noise and aerosol ejection.
- A micro-switch in the cover would prevent the operation of the grinder when the cover is not in place.
- The cover should be vibration proof.

5. Perhaps the biggest fault with the wet grinders which are presently available is the basic limitation on size and amounts of materials that may be ground. This arises from the fact that although a grinder may have a larger flywheel and more horsepower than the smaller units, the opening into the grinder is the same size as that of the smaller units. Manufacturers are aware of this problem and are in the process of producing units with larger input openings.[3]

6. A grinder should not be chosen on the basis of horsepower alone. Other factors should be considered, such as the flywheel diameter, the size of the grinder body, and the type and volume of waste to be treated.[2]

   a. Additional horsepower enables the grinder to handle heavier types of waste, but does not increase the output.

b. Larger flywheels and grinder bodies increase the centrifugal force for grinding waste which speeds removal.

II. Charging waste into the grinder

A. Special Waste Restrictions

1. "With an adequately sized disposal unit, there should be no limit to the amount or type of material which may be ground".[3]

a. Small grinders have trouble with soft plastics and rubber. These materials are not ground up, but stretch through the shear ring in large chunks, increasing the possibility of a plug. Some of these materials which float will be retained in the unit producing noise and must be removed periodically. This practice is not esthetically acceptable and can be dangerous.

b. Some material such as aluminum and brass can become impacted in the gaps in the shear ring.

c. There is a possibility of damage to the flywheel from hard metal. The metal could jam the mechanism and burn out the motor.

d. Glass and metal will hasten the dulling of rings and cutter blocks. They also produce a lot of noise when ground.

2. Radiological waste, toxic chemical waste and flammable solvents should not be charged into the grinder.

3. If infectious waste from isolation areas is to be

deposited in the grinder, the grinder should be provided with features to diminish aerosol generation which could be hazardous to the operator. An offset charging chute and a water spray directed into the grinder would help control aerosols.

B. Method of feeding waste into grinder

1. Manual feeding would probably be the method utilized in most situations.

   a. A specifically designated person should be provided to handle the feeding of waste. He should be educated on the proper operation of the equipment and the restrictions on the waste that can be charged.

      - This should diminish the breakdowns of the system due to jamming and lines being plugged.

   b. When the grinder is to be used to dispose of waste such as infectious waste or needles and syringes, the operator should be required to wear goggles and gloves to protect him when charging the waste and from any materials that might be ejected from the unit.

      - If the intake throat and grinder opening are sufficiently large, the operator should not have to handle the waste directly, (i.e. break up materials too large to fit through opening.)
      - If a water spray is directed into the grinder the possibility of materials being ejected is diminished.

III. Water and sewer connections

A. "Each model [grinder] is unique in its requirements for installation".[3] Plumbing codes and manufacturer's specifications should be checked when sizing water input lines and sewer discharge lines.

1. Water input lines should be carefully sized or clogging of sewer lines could be a frequent problem.

a. A 3/4 inch water line may be adequate for some grinders, but others may require a larger size.

2. Clogging of lines could also be a problem if waste lines are not sufficiently large. Weintraub suggests a minimum size of two inches.[3]

B. Other features of the sewer connections are important to prevent clogging.

1. The number of elbows, tees, bends, etc. should be kept to a minimum.

2. The waste line should have at least a 1/4 inch fall per running foot.

3. The size of the waste line should be maintained until it reaches larger waste lines.[1]

IV. Preventive maintenance

A. The grinding mechanisms can become dulled depending on the types of waste charged.

1. The cutter blocks should be rotated periodically and replaced when completely dulled.

a. Maintenance personnel should make sure that the cutter blocks are screwed down tightly or they could produce a great deal of noise and possibly damage the shear ring.

2. When the cutter blocks are being rotated or replaced, the shear ring should be checked. Any impacted material should be removed or the ring should be replaced if badly worn.
3. Other parts of the grinding mechanism that can be checked when working on the cutter blocks are the cutting knives which cut material as it passes through the shear ring. They will have to be replaced periodically because they bend or sometimes break.

B. The motor should be checked periodically and lubricated. Bearings and the seal will have to be replaced periodically.

C. Switches and solenoid valves should be checked periodically to insure proper operation of the system.

1. A malfunctioning time delay relay switch could cut off the water flow and cause a plug in the discharge line.
2. If the solenoid shut off valve in the water line closes too quickly, it can produce vibration and noise in the water pipes.

D. The upper housing of the grinder will have to be cleaned periodically to remove material that did not pass through the shear ring. Maintenance personnel should take care when working on the grinder and sewer lines because of the danger of injury from needles or broken glass that were retained in the grinder or sewer line elbows.

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